

Aerospace Safety Advisory Panel

Annual Report

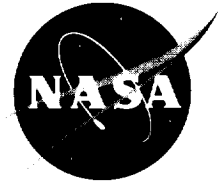
March 1995

**Aerospace Safety Advisory Panel
Code Q-1
NASA Headquarters
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National Aeronautic and
Space Administration

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Washington, DC 20546-001



Reply to Attn of:

Q-1

March 1995

Honorable Daniel S. Goldin
Administrator
NASA Headquarters
Washington, D.C. 20546

Dear Mr. Goldin:

The Aerospace Safety Advisory Panel (ASAP) is pleased to submit its annual report covering the period from February 1994 through January 1995. Overall, the Panel uncovered no "show stoppers" related to safety which is indicative of NASA's continuing commitment to risk management and reduction.

NASA's programs made significant advances during the past year. We are particularly pleased that all of the components of the Block II Space Shuttle Main Engine modifications are now underway and making good progress. Nevertheless, the safety impact of severe budget cutbacks and the departures of key personnel, particularly on labor-intensive operations such as Space Shuttle processing, continue to warrant the Panel's attention.

We remain concerned about the effective implementation of the joint U.S./Russian safety requirements. It has been difficult for us to obtain the timely and in-depth information needed to become comfortable in our oversight role of these programs. We will continue to follow the NASA collaboration with the Russians in the year to come with the specific goal of obtaining a better understanding of the joint safety processes.

The Aerospace Safety Advisory Panel appreciates the support received from NASA and its contractors. We are also grateful for NASA's timely response to last year's report. This permitted us to pursue open items in an expeditious manner. As in the past, we ask that you respond only to Section II, "Findings and Recommendations," of the current submission.

Very truly yours,

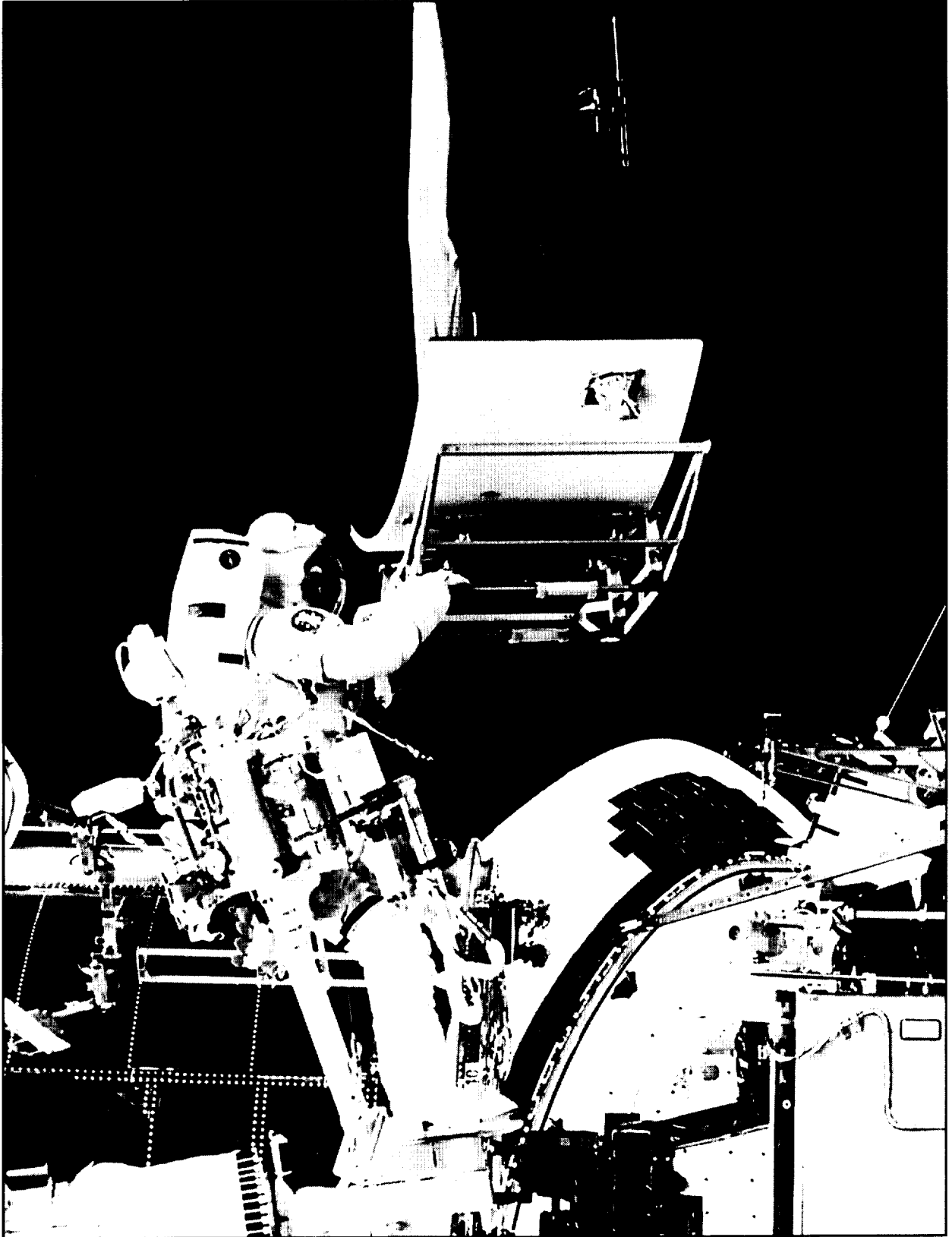
A handwritten signature in cursive script, reading "Norman R. Parmet".

Norman R. Parmet
Chairman
Aerospace Safety Advisory Panel

TABLE OF CONTENTS

	Page
I. INTRODUCTION	3
II. FINDINGS AND RECOMMENDATIONS	7
A. SPACE STATION PROGRAM	7
B. SHUTTLE/MIR (PHASE ONE) PROGRAM	8
C. SPACE SHUTTLE PROGRAM	9
Orbiter	9
Space Shuttle Main Engine (SSME)	10
External Tank	11
Solid Rocket Booster (SRB)	11
Logistics and Support	11
D. AERONAUTICS	12
E. OTHER	14
III. INFORMATION IN SUPPORT OF FINDINGS	19
A. SPACE STATION PROGRAM	19
B. SHUTTLE/MIR (PHASE ONE) PROGRAM	22
C. SPACE SHUTTLE PROGRAM	23
Orbiter	23
Space Shuttle Main Engine (SSME)	26
External Tank	30
Solid Rocket Booster (SRB)	30
Logistics and Support	30
D. AERONAUTICS	32
E. OTHER	34
IV. APPENDICES	
A. NASA AEROSPACE SAFETY ADVISORY PANEL MEMBERSHIP	A-1
B. NASA RESPONSE TO MARCH 1994 ANNUAL REPORT	B-1
C. AEROSPACE SAFETY ADVISORY PANEL ACTIVITIES	C-1

I. INTRODUCTION



I. INTRODUCTION

NASA continued its safe and productive space and aeronautics programs over the past year in spite of budget cutbacks and political uncertainties. Seven successful Space Shuttle missions added significant knowledge in science and technology and on the ability of humans to adapt to space. These flights included the repair of the Hubble Space Telescope and also laid the groundwork for rendezvous and docking with the Russian Mir Space Station. The Langley Research Center completed its work on the joint NASA/Federal Aviation Administration wind shear detection program. The results were rapidly transferred to safety improvements throughout the world. The International Space Station (ISS) began to take shape during the year as designs matured and the cooperative agreements with the Russian Space Agency and its contractors were clarified. In all, it was a year of significant incremental accomplishments, progress on long-term programs and, most importantly, safe aircraft and spacecraft operations.

The Aerospace Safety Advisory Panel (ASAP) monitored NASA's activities and provided feedback to the NASA Administrator, other NASA officials and the Congress throughout the year. Particular attention was paid to the Space Shuttle, its launch processing and planned and potential safety improvements. The Panel monitored Space Shuttle processing at the Kennedy Space Center (KSC) and will continue to follow it as personnel reductions are implemented. There is particular concern that upgrades in hardware, software and operations with the potential for significant risk reduction not be overlooked due to the extraordinary budget pressures facing the agency. The authorization of all of the Space Shuttle Main Engine (SSME) Block II components portends future Space Shuttle operations at lower risk levels and with greater margins for handling unplanned ascent events. On the other hand, delaying the incorporation of Global

Positioning System (GPS) capability in the Orbiter represents a significant lost opportunity for safety enhancements.

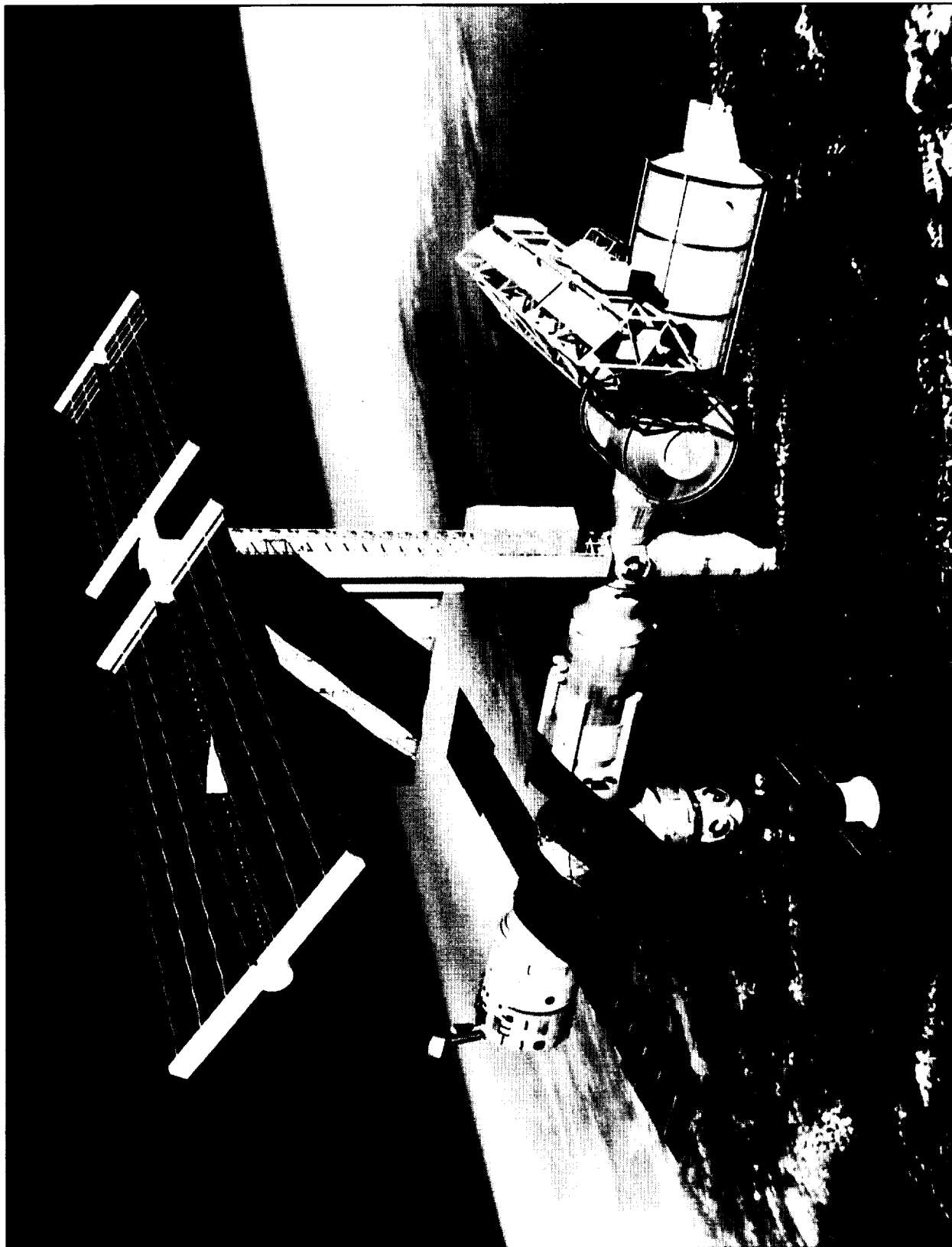
Throughout the year, the Panel attempted to monitor the safety activities related to the Russian involvement in both space and aeronautics programs. This proved difficult as the working relationships between NASA and the Russians were still being defined as the year unfolded. NASA's concern for the unique safety problems inherent in a multi-national endeavor appears appropriate. Actions are underway or contemplated which should be capable of identifying and rectifying problem areas. The Panel will monitor the joint NASA/Russian effort closely in the upcoming year. Particular emphasis will be placed on the potential for an increase in launch schedule pressure as the Shuttle/Mir missions begin. NASA must renew efforts to resist pressures to assign a launch schedule priority so high that safety may be compromised.

In the coming year, the ASAP will extend and adapt its oversight activities as needed to cover the new and revised safety challenges inherent in the continued U.S. leadership in aeronautics and the expanded habitation of space by humans.

During the year, Mr. Charles J. Donlan retired as a Panel member and became a consultant to the ASAP. Ms. Yvonne C. Brill was appointed as a member of the Panel. Mr. Paul M. Johnstone, a member of the Panel, was made deputy chairman and chairman designate.

The balance of this report presents "Findings and Recommendations" (Section II), "Information in Support of Findings and Recommendations" (Section III) and Appendices describing Panel membership, the NASA response to the March 1994 ASAP report and a chronology of the Panel's activities during the reporting period (Section IV).

II. FINDINGS AND RECOMMENDATIONS



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II. FINDINGS AND RECOMMENDATIONS

A. SPACE STATION PROGRAM

Finding #1

The original organization of the International Space Station (ISS) Program included an independent safety assessment function reporting directly to the Program Manager. Subsequently, this was changed so that independent assessment reported directly to the Associate Administrator for Safety and Mission Assurance.

Recommendation #1

Maintain the true independence of the safety assessment function by ensuring that it reports outside the Space Station Program.

Finding #2

The ISS Program has committed to providing an assured crew return capability. This will initially be accomplished by using a combination of docked Space Shuttles and Soyuz capsules. Once the ISS is permanently and fully staffed, a newly designed Assured Crew Return Vehicle (ACRV) will be deployed.

Recommendation #2

The use of the Space Shuttle and Soyuz as an interim measure is an expedient. The planned new ACRV is definitely needed to support safety in the long term. The design of this permanent ACRV, regardless of where and when it is built, should be consistent with the design reference missions and systems requirements previously defined by the ACRV Office of the Space Station Freedom.

Finding #3

The architecture of the ISS contains a Caution and Warning (C&W) system to detect and warn of malfunctions and emergencies, including toxic spills, depressurization and fire. The system makes use of laptop computers for localization of faults.

Recommendation #3

Careful consideration should be given to the appropriateness of using laptop computers for

a task as time critical as localizing life-threatening emergencies. The entire fault detection and localization process should use dedicated equipment to minimize response time.

Finding #4

The absence of experimental data for fire suppression effectiveness of the carbon dioxide extinguishers selected for use on the ISS under weightless conditions is a source of concern.

Recommendation #4

Appropriate ground-based and in-flight research to confirm the suitability of the use of pressurized carbon dioxide fire extinguishers under weightlessness should be conducted.

Finding #5

The present procedures for monitoring or controlling hazardous materials and procedures used in ISS experiments are dependent on the experiment supplier complying with Station requirements and specifications.

Recommendation #5

NASA should establish a positive system of compliance assurance modeled after the one used by the Space Shuttle Program. This system should consider the entire service life of the experiment and its deactivation when completed.

Finding #6

Good progress has been made in defining the threat from orbital debris and in demonstrating efficient shielding configurations. A technical basis for a debris protection specification for ISS is emerging.

Recommendation #6

Continue design with emphasis on: structural integrity of habitable modules and pressure vessels; identification of the damage potential from direct impact and other depressurization events; and definition and development of operational procedures and policies.

B. SHUTTLE/MIR (PHASE ONE) PROGRAM

Finding #7

The Russian Androgynous Peripheral Docking System (APDS) for docking the Space Shuttle with the Mir uses 12 active hooks on the Space Shuttle side which mate with an equal number of passive hooks on the Mir. The design currently provides no positive means of determining whether any or all of the hooks are secured. NASA has decided it is an acceptable risk to fly the first docking mission, STS-71, without an indicator.

Recommendation #7

NASA should develop an indicator system.

Finding #8

If the primary system fails, the first backup separation system for the APDS is a set of pyro bolts which disengage the 12 active hooks.

Having to rely on the pyros as presently supplied by the Russian Space Agency poses risk because of lack of knowledge relating to the pyros' pedigree and certification. A second contingency demate procedure is available involving the Extravehicular Activity (EVA) removal of 96 bolts at a different interface. Implementing either backup method to separate Shuttle from Mir may leave the Mir port unusable for future dockings.

Recommendation #8

NASA should emphasize increasing the reliability of the primary mating/demating mechanisms in order to reduce the likelihood of having to use either of the backups. NASA should also obtain an acceptable certification of the supplied pyro bolts. Failing that, NASA should procure fully certified substitute bolts.

C. SPACE SHUTTLE PROGRAM

ORBITER

Finding #9

Significant additional payload mass capability is required to meet the demands of the ISS assembly and supply plans. Much of the needed increase in capacity will be achieved through weight reduction programs on a number of Space Shuttle elements and subsystems. The large number of simultaneous changes creates potential tracking and communication problems among system managers.

Recommendation #9

Emphasis should be placed on the adequate integration of all of the changes into the total system.

Finding #10

The New Gas Generator Valve Module (NGGVM), when certified and retrofitted to the fleet, should mitigate many of the problems with the current Improved Gas Generator Valve Module in the Improved Auxiliary Power Unit (IAPU). The NGGVM development program is proceeding well.

Recommendation #10

NASA should attempt to introduce the NGGVM into the fleet as soon as possible as a safety and logistics improvement.

Finding #11

The decision has been made to install the entire Multi-Function Electronic Display System (MEDS) in each Orbiter during a single Orbiter Maintenance and Down Period (OMDP). An Advanced Orbiter Displays/System Working Group has been formed to plan for the next generation of MEDS formats and display enhancements.

Recommendation #11

NASA should support the Advanced Orbiter Displays/System Working Group and set a timetable for the introduction of enhanced display

formats which will improve both safety and operability. It should also maintain its commitment to completing the MEDS installations during a single OMDP.

Finding #12

The Tactical Air Control and Navigation (TACAN) and Microwave Scanning Beam Landing System (MSBLS) on-board receivers are obsolescent and increasingly difficult to maintain. The MSBLS receivers also have known design problems which can lead to erroneous guidance information if the Orbiter is operating with only two of the three receiver complement. A Global Positioning System (GPS) test is underway on one of the Orbiters using the backup flight software and computer. The use of GPS could replace both the TACAN and MSBLS systems as well as assisting ascent and on-orbit operations.

Recommendation #12

Given the potential of GPS to improve safety and reliability, reduce weight and avoid obsolescence and the many existing and potential problems with the use of TACAN and MSBLS, a full GPS implementation on the Orbiter should be accomplished as soon as possible.

Finding #13

Growth in the requirements for on-board data processing will continue as the Space Shuttle is used in support of Shuttle/Mir, ISS and other future missions. The length of time over which the General Purpose Computer and its software will be able to meet these growing needs effectively is likely inadequate.

Recommendation #13

NASA should expedite a long-range strategic hardware and software planning effort to identify ways to supply future computational needs of the Space Shuttle throughout its lifetime. Postponing this activity invites a critical situation in the future.

Finding #14

The STS-64 mission involved a higher than usual level of windshield hazing which could have led to a situation in which the astronauts' view of the landing runway was obscured. MSBLS and TACAN are obsolescent. There is also the possibility that false indications by MSBLS under certain scenarios could result in an unacceptable risk of a landing mishap. Thus, there is a clear need for early upgrade of Orbiter and support facility autoland equipment and crew flight rules and training improvement.

Recommendation #14

NASA should improve the autoland equipment on the Orbiter; for example, replacing MSBLS and TACAN with GPS. In the interim, NASA should ensure that operations and failure modes of MSBLS are fully examined and understood. NASA should also reexamine the training of crews for executing automatic landings, including autoland system familiarization. Astronaut commanders and pilots should discuss circumstances which might warrant autoland use prior to each mission and be prepared for all reasonable contingencies in its operation.

**SPACE SHUTTLE
MAIN ENGINE (SSME)****Finding #15**

It has become necessary to execute a partial disassembly of both the engines and turbopumps after each flight because of the accumulation of special inspection requirements and service life limits on components of the current (Phase II) SSMEs. These inspections are performed with rigor and appropriate attention to detail.

Recommendation #15

In order to control risk, NASA must maintain the present level of strict discipline and attention to detail in carrying out inspection and assembly processes to ensure the reliability and safety of the SSMEs even after the Block I and Block II upgrades are introduced.

Finding #16

The re-start of the Advanced Turbopump Program (ATP) High Pressure Fuel Turbopump (HPFTP) and the start of the Large Throat Main Combustion Chamber (LTMCC) developments were authorized in the spring of 1994. Combined with the ongoing component developments of the Block I engine, this will produce a Block II engine which will contain all of the major component improvements that have been recommended over the past decade to enhance the safety and reliability of the SSME. Both the Block I and Block II programs have made excellent progress during the current year and are meeting their technical objectives.

Recommendation #16

Continue the development of the Block II modifications for introduction at the earliest possible time.

Finding #17

In order to provide an engine health monitoring system that can significantly enhance the safety of the SSME, improvements must be made in the reliability of the engine sensors and the computational capacity of the controller. It is also essential to eliminate the difficulties with the cables and connectors of the Flight Accelerometer Safety Cut-Off System (FASCOS) so that vibration data can be included in the parameters used in the algorithms that determine engine health.

Recommendation #17

Expand and emphasize the program to improve engine health monitoring. Continue the program of sensor improvements. Vigorously address and solve the cable and connector problems that exist in FASCOS. Continue the development of health monitoring algorithms which reduce false alarms and increase the detectability of true failures.

Finding #18

The Block II SSME can improve safety if an abort is required because it can be operated

more confidently at a higher thrust level. This will permit greater flexibility in the selection among abort modes.

Recommendation #18

NASA should reexamine the relative risks of the various abort types given the projected operating characteristics of the Block II SSMEs. Particular emphasis should be placed on the possibility of eliminating or significantly reducing exposure to a Return to Launch Site abort.

EXTERNAL TANK

Finding #19

The liquid oxygen tank aft dome gore panel thickness of the Super Lightweight Tank (SLWT) has been reduced significantly on the basis of analyses. To stiffen the dome, a rib was added. The current plan to verify the strength of the aft dome involves a proof test only to limit load. Buckling phenomena cannot be extrapolated with confidence between limit and ultimate loads.

Recommendation #19

The SLWT aft dome should either be tested to ultimate loads or its strength should be increased to account for the uncertainties in extrapolation.

SOLID ROCKET BOOSTER (SRB)

Finding #20

The structural tests of a segment of an SRB aft skirt in the baseline configuration did not duplicate the strains and stresses previously measured in the tests of the full-scale aft skirt Structural Test Article (STA-3). This suggests that segment testing of the proposed bracket modification to improve the aft skirt's factor of safety may not be valid.

Recommendation #20

NASA should reassess the use of the segment test method and reconsider the use of a full scale test article for qualifying the proposed bracket reinforcement.

LOGISTICS AND SUPPORT

Finding #21

The effort by the NASA logistics organization and its principal contractors has resulted in satisfactory performance. There remain a few problems, such as a tendency towards increased cannibalization, which still require attention.

Recommendation #21

Every effort should be made to avoid cannibalizations, particularly on critical components such as the SSME and the IAPU.

Finding #22

The Integrated Logistics Panel (ILP) continues to meet at six-month intervals, usually at the Kennedy Space Center (KSC) or the Marshall Space Flight Center. The ILP serves a valuable coordinating and liaison function for the entire logistics operation. Its personnel complement has been reduced as part of the overall NASA staff cutbacks.

Recommendation #22

NASA should maintain support of an effective ILP.

Finding #23

There is a plan to consolidate all logistics elements at KSC except Spacelab over the next three or four years. This should unify the entire logistics and supply organization. The realignments are intended to eliminate duplication of effort, gain efficiency in support and materially reduce the cost of operation.

Recommendation #23

Proceed as outlined in the NASA plan.

D. AERONAUTICS

Finding #24

NASA has entered into a contract with the Tupolev Design Bureau of Russia to support flights of a TU-144 supersonic airplane for a joint U.S./Russian research program. The TU-144 has a questionable safety record, and the particular airplane to be used has not been flown for a number of years. The level of assurance available for this flight project may not be equivalent to that typically associated with NASA's flight research programs.

Recommendation #24

NASA should assure that all design and safety data and operational characteristics of this vehicle have been fully explored.

Finding #25

Wind shear encounters, while infrequent, constitute a highly significant aviation hazard that has been a causal factor in major crashes. A joint NASA/Federal Aviation Administration (FAA) Airborne Wind Shear Sensor Program has developed methods, already being implemented, for providing timely warning to aircraft in danger of encountering such atmospheric conditions.

Recommendation #25

Continue research relating to wind shear and other aircraft-threatening phenomena, such as wake vortices, and the transfer of related technologies to users.

Finding #26

NASA has a coordinated program of tire research operating from the Langley Research and Dryden Flight Research Centers. This program has the capability to provide significant safety improvements for present and future aircraft and spacecraft.

Recommendation #26

In addition to supporting the Space Shuttle and other research programs such as the High Speed Civil Transport, NASA should continue to emphasize and transfer lessons learned in the tire research effort to all segments of the user community.

Finding #27

The Dryden Flight Research Center (DFRC) has completed a demonstration of the concept of a Propulsion Controlled Aircraft (PCA) system using an F-15 aircraft flight test and an



MD-11 simulator demonstration. This system permits an aircraft to be guided to a landing in an emergency using only thrust for flight path control. DFRC is now exploring a joint program with industry to extend the demonstration to a flight test on a large commercial aircraft. Although the PCA concept has been proved, the pilot control interface aspects of the design have yet to be systematically addressed.

Recommendation #27

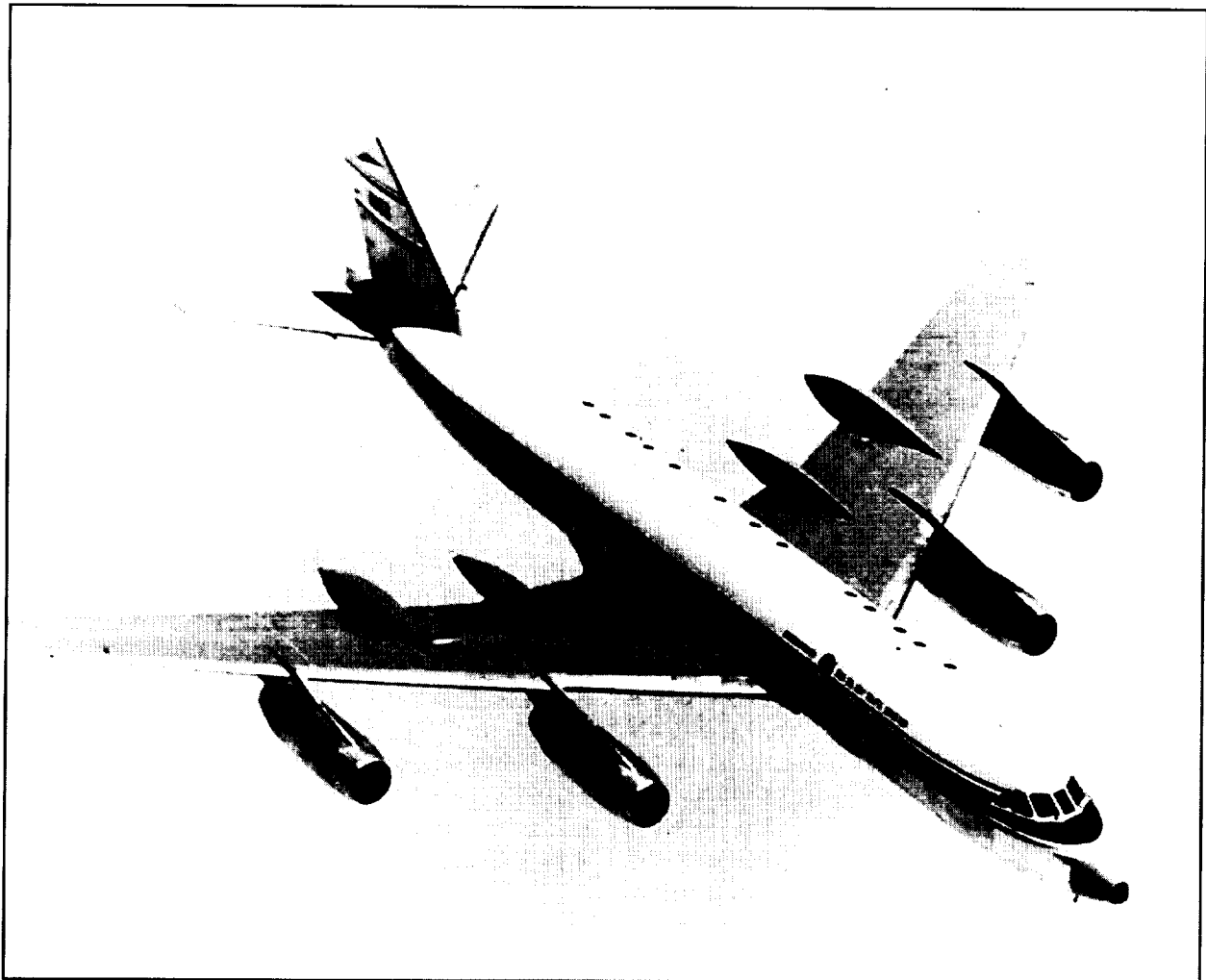
Any flight test program on a large commercial aircraft should include a strong focus on selecting the optimum pilot control interface for the system.

Finding #28

The range safety policy for Unmanned Aerial Vehicle (UAV) operations within the Edwards Air Force Base range worked when the Perseus Program suffered an in-flight failure. Range safety for Perseus flights outside of the restricted Edwards airspace has yet to be addressed.

Recommendation #28

Consideration should now be given to establishing a UAV policy to cover Perseus flights conducted outside of controlled airspace at Edwards.



E. OTHER

Finding #29

The Simplified Aid for EVA Rescue (SAFER) was successfully flight tested on the STS-64 mission. Although designed as a rescue device for an astronaut who becomes untethered, SAFER has demonstrated its potential to assist in other safety-critical situations such as contingency EVAs. Five SAFER flight units have been ordered. Plans are to deploy them on Mir and Space Station as well as to carry them on the Space Shuttle only when an EVA is planned.

Recommendation #29

Once the flight units are available, NASA should consider routinely flying SAFER units on all Space Shuttle missions which do not have severe weight limitations. This will permit them to be used for those contingency EVAs in which safety can be improved by giving crew members the capability to translate to the location of a problem to make an inspection or effect a repair.

Finding #30

NASA has established a Software Process Action Team (SPAT) to review and develop plans for addressing the software concerns that have been raised within NASA and by several review boards including the National Research Council and the Aerospace Safety Advisory Panel. While NASA has extensive procedures for addressing software issues in some arenas, these issues have not received uniform recognition of their importance throughout the agency.

Recommendation #30

NASA should ensure that computer software issues are given high priority throughout the agency and that those addressing these issues are given the support needed to produce adequate ways of dealing with them. The creation of the SPAT was an important initial step toward dealing with complex safety critical problems, but much more needs to be done.

Finding #31

There were several in-flight and ground-based episodes in which astronauts developed adverse reactions to substances used in human experiments. Although the researchers guiding these experiments submit their protocols to a standard Institutional Review Board (IRB) process, there is no independent oversight of the safety of human experiments within NASA.

Recommendation #31

NASA should provide independent oversight of human experimentation by establishing a review process in addition to the standard IRB and ensuring that the Space Shuttle and Space Station systems requirements provide sufficient equipment, staffing and training to react appropriately to any problems which might be experienced.

Finding #32

The number of reports submitted to the Aviation Safety Reporting System (ASRS) has nearly doubled since 1988 and has consistently been above the levels projected when the system was started. In these same years, budgetary resources have remained flat so that, even with significant productivity increases, the portion of incidents that receive detailed analysis has declined. In addition, ASRS has not been able to develop cost-effective electronic dissemination of advisories or a program of educational outreach to expand use of ASRS by the aviation community, both of which would be significant safety enhancements.

Recommendation #32

NASA and the FAA should restore the full capability of analysis, interpretation, and dissemination of the ASRS and promote electronic dissemination and expanded educational outreach.

Finding #33

For many years, NACA and NASA aeronautical research and flight safety benefitted from the advice and counsel provided by an advisory group of aircraft operations specialists consisting of representatives from civil and military aviation and manufacturers of aircraft, engines and accessories as well as NACA/NASA personnel.

Recommendation #33

NASA should restore the previous capacity to

capture the operational experience it found useful in improving its research focus and flight safety.

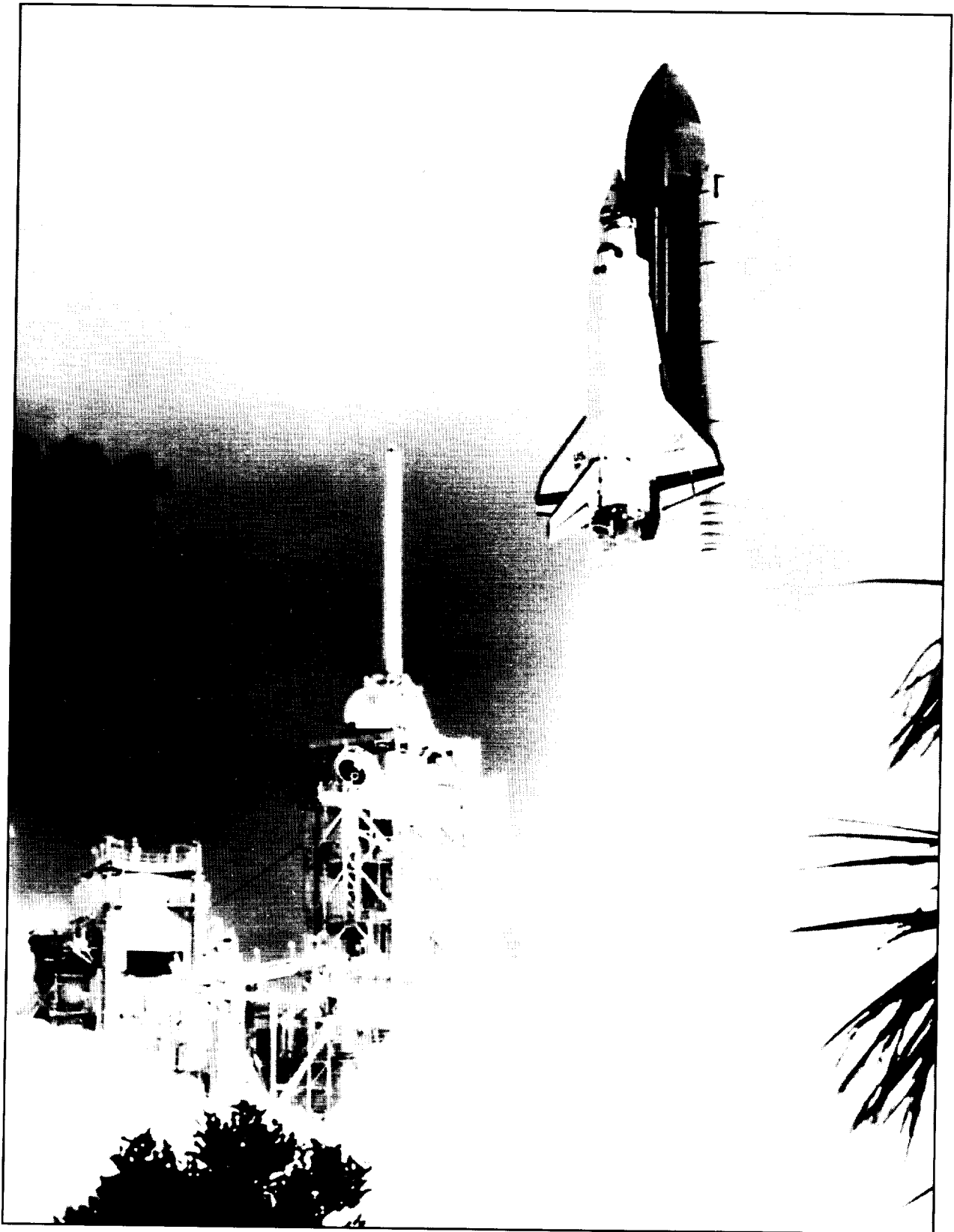
Finding #34

Total Quality Management (TQM) is an established philosophy within NASA and among its principal contractors, and implementations continue to improve.

Recommendation #34

None.

III. INFORMATION IN SUPPORT OF FINDINGS AND RECOMMENDATIONS



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III. INFORMATION IN SUPPORT OF FINDINGS AND RECOMMENDATIONS

A. SPACE STATION PROGRAM

Ref: Finding #1

The initial organization of the International Space Station (ISS) as presented to the Panel at the Johnson Space Center (JSC) placed the independent safety assessment function under the program manager. In actual fact, an independent assessment function can only be truly independent if the director of that function is established on the same organizational level as the program manager. In that way, any dispute automatically elevates to the next higher level (Associate Administrator) for resolution.

After this was brought to the attention of NASA management, the organizational structure was changed so that the head of independent assessment reported directly to the Associate Administrator for Safety and Mission Assurance (S&MA). This provides true independence for this critical function.

Ref: Finding #2

The Space Station Freedom (SSF) Program formed an Assured Crew Return Vehicle (ACRV) office to examine requirements for a dedicated spacecraft to return the crew from an orbiting space station in the event of an emergency. Three Design Reference Missions (DRMs) were identified including a medical emergency, an evacuation due to the loss of habitability of the station and a lapse in Space Shuttle logistics support. These DRMs were used to develop a set of performance requirements for an ACRV to be deployed on the Space Station Freedom when permanently crewed.

The International Space Station is a different design from SSF. Nevertheless, the DRMs remain valid as they were generic to any crewed orbiting platform serviced by launch vehicles from the earth. Likewise, the ACRV system requirements generated from the DRMs also offer valid guidance for any ACRV to be built in support of ISS.

At present, NASA has made the decision to support initial crew return efforts with a mix-

ture of docked Orbiters and Soyuz capsules. This interim approach does not fully meet the previously defined requirements for an ACRV. For example, a single Soyuz cannot accommodate the complement of a fully staffed station and has only about a six month service life on orbit. Nevertheless, this appears to be a reasonable compromise as an expedient. The long-range NASA plan is to deploy a newly designed ACRV in approximately the year 2002 when the ISS is completed and fully staffed. This vehicle, which may be U.S. built or supplied by one of the international partners, is vitally important for safety. Regardless of where it is built, its design should adhere to the systems requirements developed for the SSF ACRV. These requirements are complete and appear fully applicable as a starting point for any new ACRV. Also, in order to be available by the target date, a commitment to starting this vehicle must be made in the near future.

Ref: Findings #3 and #4

The ISS design includes systems and procedures to warn of, localize and react to a variety of malfunctions and emergencies that may occur during Station operation. The heart of these provisions is the Caution and Warning (C&W) system. This system consists of sensors distributed throughout the station which are designed to detect such things as temperatures, pressures and the presence of particulate matter within both racks and the general areas of the modules. Signals from the sensors are sent to a Multiplexer/Demultiplexer (MDM) which, acting as a data processor, discriminates between normal and abnormal conditions. The results of these analyses are sent to a set of redundant "command and control" MDMs via a digital data bus. These MDMs are, in turn, programmed to determine the nature and level of caution or warning to be issued. The resulting signals are sent to other MDMs which drive an annunciator panel in each of the five modules of the Station as well as to associated audio systems which sound alarms as required. The panels contain five

lights, three of which are programmed to indicate a specific type of emergency: fire, toxic environment and depressurization, but not the location of the emergency. In the present design, localization must be accomplished by connecting a laptop computer (via a computer port at the panel) programmed to be able to query the system as to the location and nature of the problem.

The layout of the system is reasonably straightforward and is independent of the Station's Data Management System. The fact that the laptop is apparently not dedicated to the fault localization process is a source of concern. Certainly, the time lost in making the computer connection and running the program would appear to be a waste of a precious commodity in an emergency. Also, all software used in any laptop on ISS must be configuration controlled and subjected to appropriate levels of Independent Verification and Validation.

Active attention is being paid to the possibility of a toxic spill in the station. Every precaution is to be taken in the design of containers for and in the handling of toxic substances; requirements for these safety aspects have been developed and documented and are to be levied on all users. Contingency procedures are being developed in the event of a spill and are to be part of the training program for crew members.

The possibility of fire in the Station is always present, and combustion detectors are among the sensors in the caution and warning system. Research into combustion phenomena under weightless conditions has been conducted for a number of years, and the processes are reasonably well understood. At this time the Station has selected hand-held pressurized carbon dioxide extinguishers for fire suppression. These are to be used after air circulation within a rack, for example, has been stopped. There are, however, no experimental data on the effectiveness of such extinguishers in the envi-

ronment of the Station. Experiments should be devised for both ground and flight tests to verify the effectiveness of this fire suppression technique. These can be relatively simple and straightforward with the sole objective of verifying the suppression capability of carbon dioxide in weightless conditions.

Ref: Finding #5

The Space Station's major reason for existence is to provide a platform for experimentation in space. As such, there will be great emphasis on obtaining experiments from diverse sources. These will likely include the aerospace industry, which is intimately familiar with the unforgiving nature and limitations of space, as well as sources which may or may not have any concept of the criticality of strict compliance with the requirements involved. NASA will make a grave error if inadequate means are provided to inspect and monitor the payload/experiment supplier. The Space Shuttle and some of its major payloads, such as Spacelab, already have excellent programs for specifying requirements and verifying compliance. These existing programs can serve as models for a similar ISS system.

Ref: Finding #6

Progress has been made this year in several areas related to the hazard to the ISS from orbital debris. A new assessment of the debris environment at ISS orbital altitude has led to a revised specification of the flux levels to be used for design. This specification is in the process of approval by both U.S. and Russian participants.

Several "campaigns" have been carried out this year to measure the flux of debris in Low Earth Orbit (LEO). The Haystack radar and other radars and optical sensors based at several latitudes have been employed to amass statistical data on the flux of particles 1 cm in diameter and larger in LEO. In addition, good data were obtained by launching calibration spheres in the Orbital Debris Radar Calibration

Spheres (ODERACS) experiment deployed from STS 60 in February 1994 and tracking them until they decayed from orbit. This experiment improved the ability to assess particle size on the order of 30%. Further experiments are planned for the near future to refine these figures and to introduce dipoles to better calibrate the radars in all polarizations. The overall result has been that the measured debris environment appears to be a factor of two lower at ISS altitudes (350-500 km) and somewhat higher near the 1,000 km altitude than in previously published NASA models.

The approach to evaluating probability of critical impact has been modified to account separately for each of the inhabited modules and to take notice of the reduced (compared to SSF) projected area of the current design and revised flux levels. These changes bring the "Probability of No Critical Penetration" to near acceptable levels.

NASA carried out a series of tests in the Spring of 1994 firing projectiles at hypersonic velocities (11.0 to 11.5km/sec) into shield

samples. The results of this program have led to the decision that the "Stuffed Whipple Shield" will be the standard for ISS. The Stuffed Whipple Shield is a standard Whipple shield, a thin metal plate mounted on stand-offs in front of the protected surface, modified by inserting a layer of Nextel AF62 and Kevlar midway between the plate and the surface. Such a shield proves to be superior, with respect to mass versus penetration damage, to an alternate design incorporating additional aluminum plates. This approach seems promising for protecting the ISS within mass constraints.

Protection of the ISS from debris must be considered as an overall system composed of understanding of the environment, external and internal shielding, a comprehensive avoidance system, and operational procedures to minimize the likelihood of impact as well as to react to penetration damage and possible depressurization. Such a design is being proposed, but it is still in the early stages of formulation, particularly with respect to the active avoidance system and operational procedures.

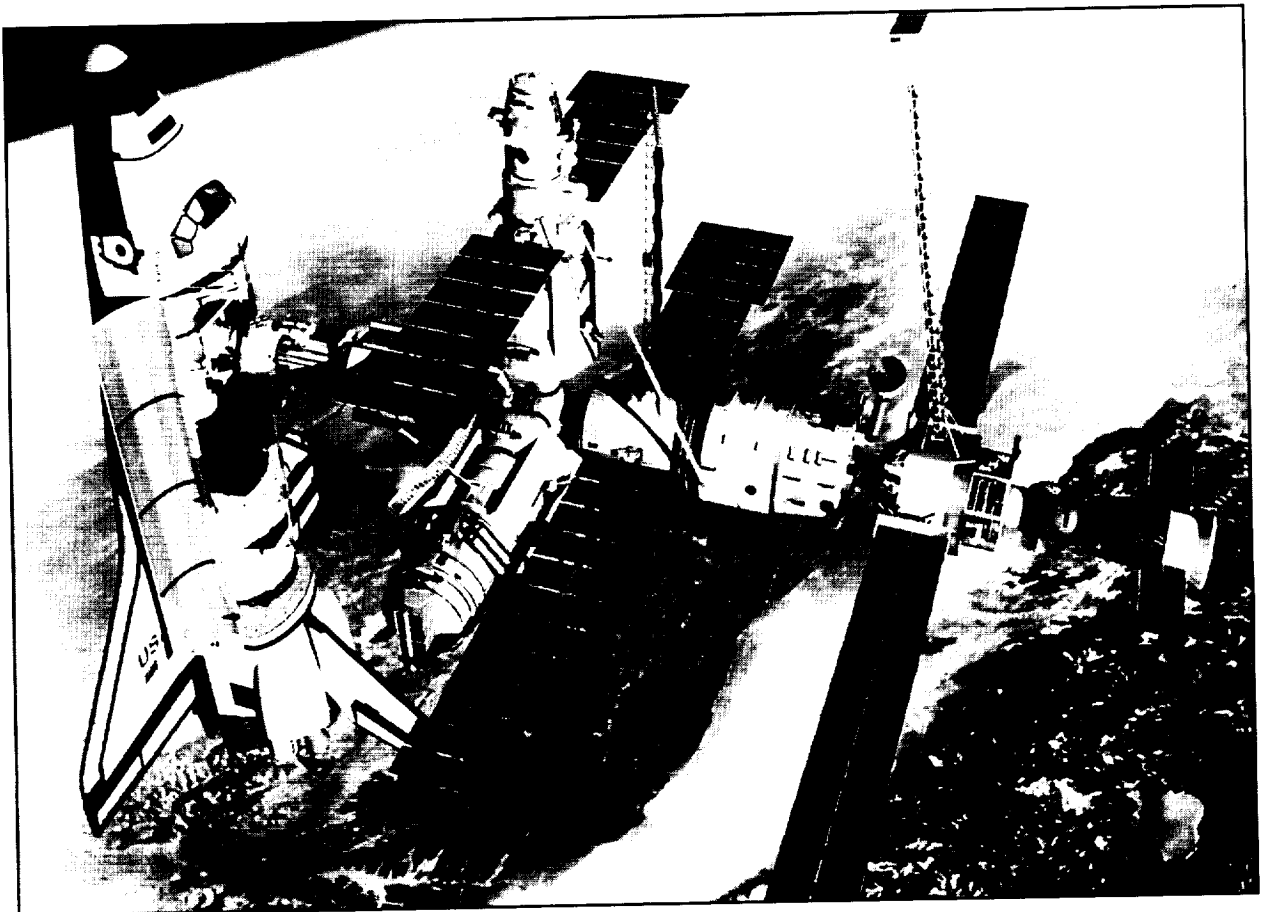
B. SHUTTLE/MIR (PHASE ONE) PROGRAM

Ref: Findings #7 and #8

The Androgynous Peripheral Docking System (APDS) joins the Space Shuttle and Mir using 12 active hooks on the Orbiter side that engage 12 passive hooks on the Mir side. It is not currently known how many latched hooks are required for safe docking security. The best that can be said is that the number is equal to or less than 12 but more than zero. The hooks operate in two sets of six each. One of the hooks in each set is activated directly by a motor which also drives a cable control assembly to actuate the other five hooks in the set. In order to release the orbiter from the Mir, the motors have to counter-rotate to disengage the active hooks. Any single failure in the system can result in one or more hooks not engaging or disengaging as commanded. The system design makes no provision to advise the flight crew or ground control of the status of each

hook, and therefore a positive docking or undocking indication is absent. NASA should implement an indicator system as soon as possible to eliminate this risk.

The first backup separation system for the APDS is a set of pyro bolts which disengage the 12 active hooks on the Orbiter side if they fail to retract. Having to rely on the pyros as presently supplied by the Russian Space Agency poses risk because of lack of knowledge relating to the pyros' pedigree and certification. A second contingency demate procedure is available involving removal of 96 bolts at a different interface by Extravehicular Activity (EVA) if the pyros do not function. In the event that either the pyro or the EVA plan to separate Shuttle-Mir must be used, its implementation may leave the Mir port unusable for future dockings.



C. SPACE SHUTTLE PROGRAM

ORBITER

Ref: Finding #9

In order to assemble the Space Station at its 51.6 degree inclination, an additional 13,000-15,000 pounds of Space Shuttle payload capability will be required for most assembly flights. The additional capacity is to be provided by a combination of weight reductions and ascent performance enhancements.

NASA has begun to analyze the thermal and structural loads environments for the Orbiter after the defined enhancements are incorporated and expects to complete the analyses in August 1995. The situation is, of course, dynamic and highly interactive. The large number of simultaneous changes creates potential tracking and communication problems among system managers. Emphasis must therefore continue to be placed on the adequate integration of all of the changes into the total system.

Ref: Finding #10

The New Gas Generator Valve Module (NGGVM) development program for the Improved Auxiliary Power Unit (IAPU) is on target for commencing fleet retrofit towards the end of 1996. The NGGVM design effectively eliminates many of the design deficiencies and Criticality 1 failure modes associated with the Improved Gas Generator Valve Module (IGGVM) which is now flying. In particular, the NGGVM: eliminates many welds and those remaining are inspectable; is designed to eliminate seat cracking problems; and has eliminated thin wall hydrazine barriers. The NGGVM design employs a spring-loaded metal-to-metal seat/poppet configuration for the pulse control valve which will reduce the safety concerns associated with seat exposure to hydrazine.

The NGGVM Design Acceptance Review was successfully completed in late July 1994. Pre-qualification testing is scheduled to begin in

the second quarter of 1995 and conclude with a Design Review in the fall of 1995. Long lead time items of qualification hardware will be started while pre-qualification is still underway (late 1995). Fabrication of qualification and production units will start in parallel at the beginning of 1996 to support commencing fleet retrofit late in that year.

The NGGVM test plan has been greatly truncated based on recommendations of an expert team. The reduction from the originally planned 375 hours of testing to only 98 hours will save cost and time. The rationale for this reduction appears sound and consistent with a safe level of operations.

The program has examined three alternative plans for introducing the NGGVM into the fleet. The first strives for the *earliest possible* incorporation. It would have all APUs upgraded to the NGGVM by roughly the end of 1997. The second plan is *attrition-based* and would only upgrade the valve in an APU when the unit was already scheduled for overhaul. This would delay complete fleet introduction until approximately the year 2000. The third plan, which is the present plan for introduction, is *opportunity-based*. The ground rule of this plan is to maintain a predetermined minimum Kennedy Space Center (KSC) stock level of spare IAPUs during the modification cycle to support any unplanned removals. Any removed IAPUs not needed to support the minimum stock level will be shipped to the manufacturer for the NGGVM upgrade. Under this plan, NASA indicates that the NGGVM modifications can be completed in late 1998 or early 1999.

The problem with the *earliest possible* incorporation plan is that it must appropriate flight assets from the KSC. The projected result, assuming no unplanned removals, is that there will be fewer than a shipset of spares on hand at KSC for virtually all of 1997 and one quarter of 1998. In fact, for two quarters of 1997 a

position of zero spares is projected. The low spares count means that any unplanned removals could force cannibalization to keep the fleet flying. This is a highly undesirable situation which mitigates against adopting the *earliest possible* introduction plan. Including the IAPUs on whichever vehicle is undergoing its Orbiter Maintenance and Down Period (OMDP) at Palmdale in the spares count provides only minimal relief for this problem.

The *attrition-based* plan delays introduction and hence the availability of an important safety and logistics improvement. The *opportunity-based* plan, while a compromise, may still be associated with an unacceptably high chance of the need for cannibalizations to support flight.

There is a possible way to reduce or eliminate the potential for cannibalizations with the *earliest possible* or *opportunity-based* introduction plans at an additional cost. There are four baseline APUs in storage which were not upgraded to IAPUs with the balance of the units. The program assets include spare IAPU components sufficient to upgrade three of these baseline units to IAPUs, although this would significantly reduce the parts inventory. If a timely commitment for this conversion is made, the additional IAPUs would be available to support NGGVM introduction. Although this would not move up the completion date for either plan, it would ensure that at least a full shipset of spare IAPUs was available at all times.

Given the manufacturing problems with the IAPU which surfaced during 1994 and the extent of hands-on labor needed to keep them flying, NASA should carefully consider all of the facets of the adopted NGGVM introduction plan and give appropriate emphasis to the avoidance of possible cannibalizations or the need for unplanned IAPU removals from Orbiters during their OMDP.

Ref: Finding #11

A Multi-Function Electronic Display System (MEDS) with enhanced quality and functionality of displays has great potential to reduce workload, improve crew response time, reduce crew training requirements and provide the crew with better information for both normal and contingency operations. These capabilities could be extremely important for the safety of proximity operations with Mir or the Space Station. They will also be invaluable in the event of an abort situation.

The initial plan was to install the foundation for the MEDS during an OMDP and to complete the installation during normal flows at KSC. In addition, the displays on the initial MEDS implementation were to emulate the existing electro-mechanical devices in both format and information content. Both of these decisions delayed achieving the full safety and operational benefits of which the MEDS is capable. The Shuttle Training Aircraft and training simulators are also to be upgraded to a MEDS configuration.

The Space Shuttle Program has now decided to install the entire MEDS system during a single OMDP. Under this plan, an Orbiter will arrive in Palmdale with conventional instruments and leave with a full "glass cockpit" installation. This represents a significant improvement in the installation strategy and eliminates a myriad of problems associated with a two-step transition. It has also been decided to depart somewhat from a strict emulation of the old displays, although a fully developed MEDS format has been deferred until a later generation of the system.

NASA has committed to a future phase of Orbiter displays-and-controls update activities in order to achieve a state-of-the-art system. This effort should include both enhancements to the display formats themselves and the quantity and nature of information presented.

Display format improvements for the existing set of displayed information can be achieved within the programming of the MEDS itself. Changes in the type of information presented will require modifications to the General Purpose Computer software. An Advanced Orbiter Displays/System Working Group has been formed to plan for the next generation of MEDS formats. This group has a limited budget and no firm deadlines. Given the potential benefits from a fully-enhanced MEDS, it would seem best for NASA to plan a firm schedule for MEDS upgrades and to support the working group to the maximum extent possible.

Ref: Finding #12

The full Microwave Scanning Beam Landing System (MSBLS) installation on the Orbiter includes three receivers, although only two must be operating in order to launch. When one of the three receivers fails to provide a correct output, it is taken off-line. This first failure is easy to identify when all three are on-line since the failure logically takes place in the receiver with a signal that differs from the other two or, if a logic flag within the receiver identifies a fault in that unit.

With only two receivers on-line, certain failures may be identified by a flag or by the Orbiter's on-board computer logic, but the probability of any failure being detected is not very high. With the current Orbiter system installation the two remaining receiver outputs are averaged and this signal is used as a navigation input during the final approach, flare and landing. If one of the two receivers fails during this time, the averaged output will obviously change and the MSBLS output will be in error. Flying with only two MSBLS receivers would be adequate for mission success provided that the flying pilot can visually monitor the final approach and landing to determine if the remaining MSBLS receivers are providing accurate guidance information.

The Global Positioning System (GPS) could avoid the above deficiencies and thus enhance the operational performance and safety of the Orbiter. There are two distinct aspects of considering GPS as a replacement for MSBLS. First, MSBLS is not only obsolescent but also possibly could become a safety issue because of the great difficulty in maintaining very old electronic airborne units. Second, there is the considerable expense involved in maintaining a network of MSBLS ground stations at all landing and primary abort sites. The ability of the Orbiter to navigate independently for approach and landing using GPS could also significantly increase the number of contingency abort sites available.

The Federal Aviation Administration (FAA) has already announced that GPS may soon be used as the sole navigation source by the airlines. Non-precision approaches using only GPS have already been approved, and precision approaches will almost certainly follow soon.

The issue of MSBLS seems abundantly clear. The performance and safety enhancements that GPS can offer to Orbiter performance in ascent, aborts, on-orbit operations and approach and landing warrants its installation as soon as possible.

Ref: Finding #13

Throughout the history of the Space Shuttle program, there has been a continuing demand for upgrades to the functionality achieved with the on-board General Purpose Computer (GPC) system. This increase in functionality has been achieved through upgrades to the GPC software with the exception of a single GPC hardware upgrade which took over eight years to implement. Almost every flight sees some level of software change, and at somewhat larger intervals, major upgrades to the software take place. There has been a general tendency for the memory and processor requirements to grow during this continual software upgrade process.

As early as 1983, NASA recognized the need to upgrade the computational capabilities in the GPC hardware, and began a program to replace the original processors and memory. In 1991, NASA began use of the "new" GPC. However, the new GPC achieved considerably less additional memory usable for active flight control software than originally expected due, in part, to the non-modular arrangement of the Space Shuttle software.

Upgrades to the Space Shuttle software continue, but at a slower rate than before. There are concerns within NASA that important safety-related software upgrades are being postponed because of the complexity associated with changing the non-modular software. Moreover, at some point, the new GPC memory will be filled, making further upgrades much more difficult, or, perhaps, even impossible. Little analysis has been conducted on the long term impact of continuing demands for performance improvements and the ultimate limits of the current processors.

Attention to date on computer related functionality has been largely focussed on the GPCs and their memory. However, other avionics components, such as the MDMs, are also growing older, with an attendant concern over maintainability. Concerns have been expressed over how much longer they can be used.

While the situation with respect to the Space Shuttle computer and avionics systems has not become critical, there are at least two major concerns. First, the GPC is gradually approaching saturation. Second, the time required for any major upgrade in computer/avionics hardware or redevelopment of the basic flight software is very long, on the order of a decade. Therefore, NASA should begin a long range strategic hardware and software planning effort on ways to supply future computational needs of the Space Shuttle throughout its lifetime. Postponing this activity invites a critical situation in the future.

Ref: Finding #14

The ASAP has long advocated that more attention be paid to the existing autoland function on the Orbiter. At present, the capability exists and crews are aware of it. They do not, however, train for executing an autoland. They also do not engage in a formal process to examine topics related to autoland engagement and disengagement. These topics would include such things as conditions under which an autoland was the preferred mode and how and when a manual takeover should be accomplished if necessary during an automatic landing. The Panel is simply proposing that crews receive a reasonable level of training and system familiarity so that autoland becomes a true contingency possibility rather than a capability with a remote chance of being used even if needed. NASA should also improve the autoland equipment on the Orbiter; for example, replacing MSBLS and TACAN with GPS.

SPACE SHUTTLE MAIN ENGINE (SSME)

Ref: Findings #15 through #17

PHASE II ENGINE: The current SSME systems ("Phase II") have performed well in flight during the past year. However, a number of new and/or heightened concerns have arisen. Among them is an increased incidence and severity of "sheetmetal" cracks (or peeling) in the High Pressure Fuel Turbopump (HPFTP) turn-around and inlet ducts. This has resulted in the need for increased inspections to tighter limits as well as redesign of the sheetmetal of the inlet duct including a change in its manufacturing technique. It was also discovered that the turning vanes in the High Pressure Oxygen Turbopump (HPOTP) preburner volute diffuser had undersized (out of specification) fillet radii, a condition that enhances the probability of fatigue failure. This has resulted in a Deviation Approval Request (DAR) being issued limiting the number of turbopump starts and runs between removals

for refurbishing. All told, as a result of the accumulation of DARs, it is now necessary to remove and at least partially disassemble the engine and turbopumps after each flight. The continuing need for additional special inspections and service time limits confirms the validity of the decision to commit to the major engine improvements that have been undertaken—the Blocks I & II programs discussed later in this section.

There was a launch abort caused by a violation of the start limit for the HPOTP turbine exhaust temperature (1,560 degrees F) on an engine during the initial launch attempt for the STS-68 mission. The control system performed as designed during this abort and shut down all three SSMEs prior to solid rocket motor ignition. A thorough investigation of the incident led to the conclusion that there had been a concatenation of a number of factors, none of which individually would have caused the over-temperature, that led to the shutdown. These factors included, among others, a Main Combustion Chamber (MCC) that had above normal leakage and a flowmeter that exhibited a calibration shift during its first acceptance test but performed normally thereafter. The engine containing the pump that caused the shutdown was removed from the vehicle and sent to the Stennis Space Center for test firing. Care was taken to ensure that there were no changes in its configuration. The engine performed normally in the test. A review of the methodology used to set the start and flight redlines is continuing.

Sensor failures continue to be a problem. They are mitigated somewhat by the use of redundant instruments and controller logic. Some actions have been taken to improve the reliability of the current sensors. For example, new pressure sensor inspection techniques are being employed to help detect and eliminate particulate contamination. Flux contamination of the cryogenic temperature transducers is being eliminated by changes in manufacturing

and inspection techniques and sequences. Hot gas temperature transducers using thermistors as the principal sensor will be replaced by a more rugged thermocouple-based sensor.

BLOCK I ENGINE: The Block I engine improvement program is proceeding very well. The Block I engine includes the new two-duct powerhead, the single tube heat exchanger and the Advanced Turbopump Program (ATP) HPOTP. The first two of these major changes have flawlessly completed certification tests. The first unit of the ATP HPOTP has completed initial certification testing accumulating 10,000 seconds of run time in 22 test runs and is into its second series. These tests included considerable time at 109% thrust as well as a margin demonstration at 111%. The unit was disassembled after these tests and only minor wear was observed. The turbine blades and the silicon-nitride ball bearings were in excellent condition and can be re-used. One roller in the roller bearing had slight wear indicating contact with the end rail of the bearing—a minor problem. There was some delamination of the honeycomb structures that serve as part of the labyrinth seals between stages of the turbine. No performance degradation was observed and the phenomenon poses no danger to the machine. This wear can be remedied by minor design changes. The second HPOTP unit had completed its first series of tests and has accumulated 10,000 seconds of run time without any problems as of the time of this writing.

As part of the HPOTP program it was necessary, for proper matching of the boost and main pumps in the oxygen system, to redesign the angle of the inducer blade of the Low Pressure Oxygen Turbopump (LPOTP) that feeds the HPOTP. This change is straightforward and was achieved without difficulty. While this was being done, the current (Phase II) LPOTP began to exhibit excessive ball wear in its thrust bearing. The solution adopted for the new LPOTP is to employ silicon-nitride balls in this bearing. Serendipitously, these

balls are the same size as those employed in the HPOTP making the change simple to implement.

In total, the Block I engine development and certification is proceeding well and is on schedule for its planned introduction into the fleet in the first half of 1995.

BLOCK II ENGINE: This engine version comprising the Block I changes plus the Large Throat Main Combustion Chamber (LTMCC) and the ATP HPFTP is also proceeding well. Go-ahead for the re-start of the HPFTP and the start of the LTMCC development was given in the spring of 1994 thereby completing the scope of the program of major component redesign and development that had been recommended for over a decade. The LTMCC, which is considered by many to be the most significant safety improvement in the SSME, is ahead of its manufacturing plan, and a development unit has been shipped for test. A development unit of the HPFTP has also been assembled using parts that had been made before the activity was put on a stop-work status. At the time of this writing, a complete Block II development engine had been assembled and a full duration test run (including operation at 109%) had been completed. The preliminary data review from this test showed that the performance objectives predicted were achieved and that there were no systems integration problems evident. The first "final" configuration HPFTP is scheduled for delivery in the spring of 1995. The limiting factor in the delivery schedule is the time to develop and produce an improved fine-grain casting that should eliminate some cracking that had occurred in the earlier version. Other changes such as decreasing the turbine flow area by increasing the number of turbine nozzle vanes are to be delivered with adequate lead time. The increase in the number of turbine nozzle vanes also detunes the excitation of the first stage turbine blades and should preclude the cracking experienced at the trailing edge of the blade tip.

HEALTH MONITORING: As noted in last year's report, it would be advantageous to develop the engine controller and associated software and sensors into a true and more effective "health monitoring system." Such a system would ideally reduce both the probability of shutting down a healthy engine and the probability of failing to detect an engine malfunction in a timely manner. Improved health monitoring would reduce the risk involved in engine operation. To accomplish this requires not only development of suitable algorithms but also improvement of the reliability of sensors and increasing the computational capacity of the controller. The improvement of sensors was discussed earlier in this section. Regarding the controller, during the past year it was found that it was subject to "single event upsets" due to cosmic ray strikes either during flight or on the ground. This eventuality was believed so remote during controller design that "radiation hardened" solid state electronic devices were not selected. It would be advisable to substitute such hardened devices for existing hardware to reduce risk. While this is being accomplished, it appears possible simultaneously to increase computational speed by adding a co-processor. This would permit the controller to perform the added functions required for improved health monitoring without a major redesign and re-manufacture.

Studies have been conducted to define the algorithms that would be needed to enhance engine health monitoring. It was found, that with the current complement of sensors (i.e., pressure, temperature, valve position, and speed) and computational power it was not possible to effect any significant improvement in the health monitoring function effectiveness. It was determined that if engine vibration were added to the inputs to the system along with the previously mentioned co-processor, significant improvements could be made as parameters of this type can give early warning of severe malfunction. Accelerometers measuring these variables already exist on each

engine in the Flight Accelerometer Safety Cut-Off System (FASCOS). The instruments themselves appear to have requisite reliability, but cables and connectors that transmit their signals do not. Their reliability is so low that the information transmitted cannot be trusted. Correcting these problems should be pursued and, when successful, the development of a modern health monitoring system (similar to those employed in jet aircraft) should be undertaken.

Ref: Finding #18

Space Shuttle operations planning includes provisions for a variety of aborted flight situations in the event of the failure of one or more SSMEs. The particular abort mode to be flown is dependent on the number and timing of SSME failures. Loss of a single SSME leads to one of a series of abort modes known as *intact* aborts. The first of these is the Return to Launch Site (RTLS) abort. It results from the early shutdown of an engine which yields a trajectory without sufficient energy to reach even a Transoceanic Abort Landing (TAL) site. RTLS is currently the only intact abort possible with a single engine failure in approximately the first 160-175 seconds of flight.

If a main engine is lost in the middle of powered flight (from approximately 175 seconds to 300 seconds), the Space Shuttle can fly to a TAL site at Ben Guerir, Morocco; Moron, Spain; or Banjul, The Gambia. The powered flight, external tank separation and entry profiles of the TAL more closely approximate the normal flight profile than do the unusual flight path and maneuvers of RTLS.

When sufficient energy is achieved, the Space Shuttle has the capability to abort by flying once around the earth and landing at Edwards Air Force Base, White Sands Space Harbor or the Shuttle Landing Facility (SLF) at KSC. This is known as an Abort-Once-Around (AOA).

The loss of SSME thrust late in the trajectory still permits the Space Shuttle to Abort-to-Orbit (ATO) at a minimum altitude of 105 nautical miles. The mission can then be continued or terminated "normally" with a deorbit burn and landing.

Loss of two SSMEs results in a *contingency* abort situation. This can require the Space Shuttle to land at a contingency landing site or necessitate a bail-out or ditching. The availability of suitable contingency landing sites is dependent on the inclination of the launch (intended flight path) and timing of the second engine failure. In general, if a second failure occurs while the Space Shuttle is already flying an RTLS maneuver, Bermuda, one of the preferred contingency landing sites, cannot be reached.

Any abort increases risk over normal flight. Therefore, although each of the intact abort types has been "certified" by analysis, avoiding abort situations, especially the more unusual aborts which do not approximate a normal flight profile, is desirable. Hence, ATO is clearly the preferred mode since it is really a quasi-normal operation. The STS 51-F mission executed an ATO when an engine was shut down prematurely late in flight due to a sensor failure. It continued uneventfully and achieved many of its objectives even though the intended orbit was not reached.

RTLS raises several particular concerns because of the unusual flight profile which must be flown. After the Solid Rocket Boosters (SRBs) are separated, the Space Shuttle must continue flying to dissipate propellants in the External Tank (ET). While dissipating propellants, a powered pitcharound must be performed so that the Orbiter is literally flying backwards with the thrust of the remaining SSMEs being used for braking. This is followed by a powered pitchdown before main engine cutoff and ET separation.

The Space Shuttle then executes a pullout and enters the region of Terminal Area Energy Management. The RTLS concludes with heading alignment and a landing at the SLF. The unusual RTLS maneuver leads to several concerns such as overheating from flying into the SSME plume and extremely complex flight mechanics.

Previous examinations have been made of what is required to eliminate or reduce exposure to RTLS by achieving TAL capability sooner in the ascent profile. In general, reducing or eliminating RTLS exposure requires changes in entry trajectory ("stretched entry") as well as an SSME *abort* throttle setting above the typical 104% level (at least 109%). For the present engine configuration, the use of 109%, even in an abort situation, was considered undesirable because of the inherent reductions in operating margins at the higher thrust. The upcoming Block II engines, however, are designed to operate at a 109% power setting with margins comparable to (or better than) the current SSMEs at 104%.

In light of the operating flexibility offered by the Block II engines, it would appear prudent to reexamine the entire issue of aborts in detail. Eliminating RTLS should be one objective of this review. The resulting risk reduction and improvement in launch probability would represent significant benefits to the Space Shuttle and ISS programs.

EXTERNAL TANK

Ref: Finding #19

The Super Lightweight Tank (SLWT) is being designed and built for the Space Shuttle to provide a large proportion of the weight savings needed to accommodate the increased payload requirements of the ISS. The liquid oxygen tank aft dome gore panel thickness of the SLWT has been reduced significantly from its initial design on the basis of analytic results. To stiffen the dome, a rib was added.

The current plan to verify the buckling strength of the aft dome involves a proof test only to limit load. This will permit the test hardware to be reused. The problem is that buckling phenomena cannot be extrapolated with confidence between limit and ultimate loads. Thus, the proof test will only demonstrate that the structure will withstand limit load without buckling. In order to provide a sufficient level of confidence, the SLWT aft dome should either be tested to ultimate loads or its strength should be increased to account for the uncertainties in extrapolation.

SOLID ROCKET BOOSTER (SRB)

Ref: Finding #20

The addition of an external bracket to the aft skirt of the SRB has been proposed to restore the factor of safety to 1.4. The effectiveness of this modification was to be tested using segments cut from an aft skirt and loaded so that the boundary conditions of stress and strain duplicated those encountered in a previous full scale test of an aft skirt (the "STA-3" test). The first step was to duplicate the baseline conditions with an unmodified segment. This test did not successfully repeat the stresses and strains measured in the STA-3. This suggests that segment testing of the proposed bracket modification to improve the aft skirt's factor of safety may not be valid.

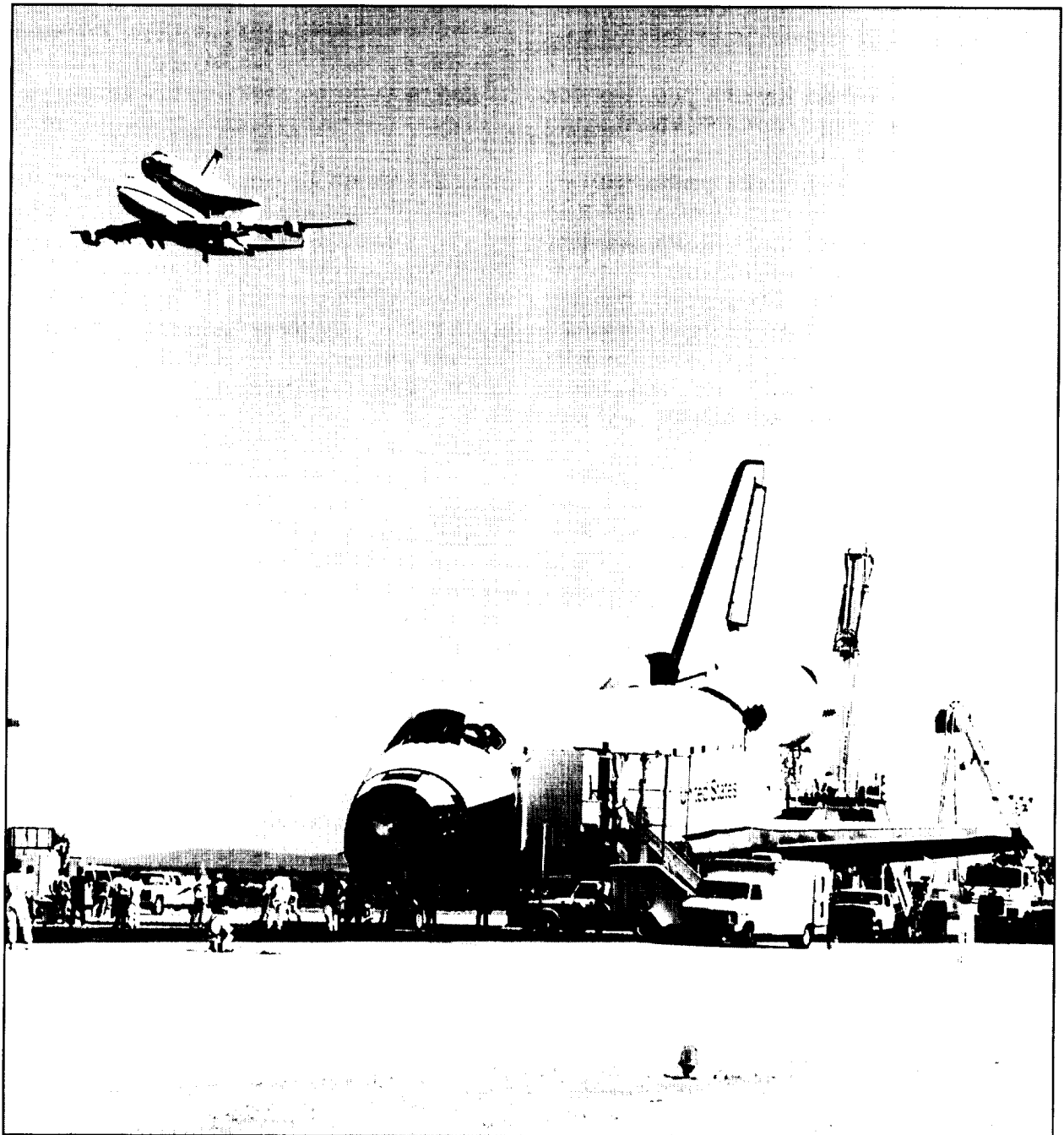
LOGISTICS AND SUPPORT

Ref: Findings #21 through #23

The principal logistics performance measurements such as cannibalization, shelf fill rates, zero/below minimum balance and repair turnaround time showed good to excellent results this year. Cannibalization has shown the expected response to the control being exercised, but is still not at zero and is therefore of concern. The reporting and control systems have reached a mature stage and appear to be very satisfactory for all Space Shuttle elements.

A major effort toward consolidation of logistics activities at KSC has recently been announced which should optimize spares levels, eliminate functional duplication and centralize control and administration. A group has been established to study and recommend final organizational and functional realignments.

The overall benefits of a comprehensive consolidation such as the reduction of unnecessary duplication at KSC are apparent. The decision to omit the Spacelab logistics from the new system appears wise as its requirements and structure are unique and the program is nearing completion.



D. AERONAUTICS

Ref: Finding #24

NASA has entered into an agreement with the Russian Tupolev Design Bureau to support a set of research flights on a TU-144 supersonic airplane. The TU-144 has a questionable safety record, and the particular airplane to be flown has been "mothballed" for years. The level of assurance available for this flight project may not be equivalent to that typically associated with NASA's flight research programs.

The TU-144 program has the potential for assisting in validating design codes used in the High Speed Civil Transport (HSCT) efforts and can thereby reduce the probability of making costly mistakes. However, this depends upon a well conceived program that correlates the data derived from the flight program with predictions. The currently planned experiments include boundary layer measurements, handling quality assessments, propulsion system thermal environment, sonic boom signatures, cabin noise and temperature prediction verifications.

Before the flight program is to be conducted, the aircraft will undergo significant modifications. In addition to being returned to flight status after a long period of storage, the plans include replacing the original engines with a different type adapted from the Blackjack bomber. This will require adapting new nacelles and a digital engine controller. In light of the changes and uncertainties involved in the TU-144 flights, NASA should assure that all design and safety data and operational characteristics of this vehicle have been fully explored.

Ref: Finding #25

Wind shear is created during an atmospheric phenomenon known as a "microburst." This consists of a powerful downdraft that cascades earthward creating rapidly shifting winds. An airplane flying into such a condition can suddenly encounter winds that can reduce air-

speed to a hazardous level. Wind shear is a major safety concern even though it occurs infrequently. It has been a causal factor in at least 27 U.S. aircraft accidents between 1969 and 1985 and has been cited as the cause of over 50 percent of accident fatalities in the 1975 to 1985 period. Close calls continue to be reported; the risk still exists.

A National Integrated Wind Shear Program Plan was initiated by NASA and the FAA to develop methods for detecting this atmospheric phenomenon and providing timely information to aircraft in imminent danger of encountering this hazardous condition. The program consisted of three principal elements: (1) hazard characterization—wind shear physics, heavy rain aerodynamics, impact on flight behavior; (2) sensor technology—airborne doppler radar and other instrumentation; and (3) flight management systems—requirements, displays, pilot procedures.

In operational use, the system displays in the cockpit a *predictive* wind shear hazard index. The FAA has already published system requirements and certified certain technologies for implementing the system. All national and international carriers will be required to have such a wind shear detection system in the near future—as early as December 1995. The U.S. Air Force already requires this capability on all its transport and tanker aircraft.

The wind shear program is a good example of a productive cooperative research program. Although the work has already been transferred into operations, there is more to be done on the subject of wind shear. For example, radar frequencies other than the X-band which is currently employed might profitably be investigated. Therefore, continued support of research relating to wind shear and other aircraft-threatening phenomena, such as wake vortices, and the transfer of related technologies to industry appears warranted.

Ref: Finding #26

NASA has had a long history of research supporting industry's efforts in tire design and operation. Through the years, aircraft performance has continued to increase placing greater reliance on tire design for safe high speed operation, and for durability in service. Although significant progress has been made, much work remains. Supersonic aircraft, and in particular the future HSCT will require even higher performance from its tires. The Space Shuttle has tires that require replacement after each flight. Thus, there are continuing safety and economic reasons for additional research aimed at developing improved tire materials and designs.

NASA's tire program operates from the Langley Research Center using the Aircraft Landing Dynamics Facility and from the Dryden Flight Research Center (DFRC) using the Convair 990 Landing Systems Research Aircraft. The combination of a flying testbed and a ground-based facility provide researchers with excellent flexibility to study important tire issues.

Ref: Finding #27

The Dryden Flight Research Center has completed a demonstration of the concept of a Propulsion Controlled Aircraft (PCA) system using an F-15 aircraft flight test and an MD-11 simulator demonstration. The PCA system permits an aircraft to be guided to a landing in an emergency using only differential thrust for control. This might have prevented a crash such as the one experienced by the DC-10 at Sioux City, Iowa. With the successful landings in the F-15 and demonstrations with airline pilots in the simulator, the PCA program has clearly progressed beyond the proof of concept stage and identified the potential safety benefits from a full-scale development and deployment of this concept. Now that the concept has been proved and before it is tested in a

commercial transport, it is appropriate to address the *total* system design of propulsion control. This should include a strong focus on defining and designing the optimum pilot control interface for the system. A basic concern is that an assumption appears to have been made that the standard Mode Control Panel is the appropriate interface. This may not be correct. For example, if a pilot must make any manual throttle inputs, using the Mode Control Panel at the same time could be awkward. For this and other reasons, other control approaches, particularly the use of the standard controls (yoke or sidestick) should be carefully considered. This would result in a control approach similar to the *Control Wheel Steering (CWS)* mode available on many current aircraft.

Ref: Finding #28

The Perseus Program involves Unmanned Aerial Vehicles (UAVs) for environmental research. Last year, the Panel recommended development of a range safety policy at DFRC to be applied to UAVs. Dryden did indeed develop such a policy in coordination with the Edwards Air Force Base (EAFB) test range. This policy had to be applied to a Perseus flight on November 21 when the vehicle diverged at 35,000 feet. The vehicle was lost, but range safety was not compromised. The vehicle crashed in the prescribed range safety area.

Dryden is responsible for operating Perseus flights. An investigation team has been appointed by the Center Director to review this incident. Since the intended use of these vehicles is to provide a research platform for studies in atmospheric science, the Perseus will ultimately have to fly outside of the EAFB protected area. In fact, UAVs such as Perseus may operate in both national and international airspace. Dryden cannot take responsibility alone for these flights. Other U.S. and international governmental authorities must be involved.

E. OTHER

Ref: Finding #29

The Simplified Aid for EVA Rescue (SAFER) is a small maneuvering unit intended to fit at the bottom of the Portable Life Support System (PLSS) of an EVA astronaut. Its design purpose is to permit an astronaut who becomes untethered from the Space Station or a Space Shuttle to return safely. This potential problem is not considered great for a free flying Shuttle since it can maneuver immediately to retrieve an astronaut who is drifting away. It can be serious, however, if the Space Shuttle is attached to the Space Station or another satellite and is not free to maneuver quickly.

In addition to astronaut rescue, there are also contingency situations which cannot be resolved at present because an EVA astronaut is unable to maneuver to the source of the problem. For example, if there were an indication that an ET umbilical door on the Orbiter had failed to close, the crew would have no way to perform a visual inspection to confirm the validity of the warning.

Since SAFER was designed primarily for rescue, it does not include the degree of redundancy typical of human-rated flight systems. It was reasoned that a single string system would be adequate for rescue objectives. However, this lack of redundancy appears to have deterred NASA from expanding the use of SAFER to the contingency situations in which it can be a significant benefit.

Five flight units have been ordered. Three of these will be deployed on the Mir and Space Station. The two remaining units are to be flown on the Space Shuttle only when an EVA is planned. This deployment strategy does not make full use of the safety benefits of flying SAFER. Given that a problem has occurred such as an indication of an unlatched ET door or the suspicion of tile damage, it would likely be an acceptable risk to employ a SAFER unit

to inspect or correct the situation. In general, if there is the possibility of a corrective or confirmatory action to increase flight safety, the small additional risk arising from the lack of redundancy in SAFER can be tolerated.

Based on these considerations, it would appear reasonable to carry one or two SAFER units on all Space Shuttle missions once the flight units are available. These units are relatively light weight and have minimal logistics requirements. They stow in the airlock on the PLSS, so they do not require any Orbiter modifications. The availability of the SAFERs will provide mission planners with a significant increase in flexibility to handle contingencies which might arise. The only exception to the general deployment of the SAFERs would arise on those missions which are severely weight limited and do not have any planned EVAs. NASA should examine the logistics and costs associated with a more widespread use of SAFER, and, if necessary, procure additional flight units to support an expanded role for SAFER.

Ref: Finding #30

Over the past several years, NASA has received recommendations from the General Accounting Office, the ASAP and the National Research Council among others stating that the agency needed to give greater attention to potential software problems. Early in the year, NASA established a Software Process Action Team (SPAT) to review and develop plans for addressing the plethora of software concerns that have been raised. The problem with the initial implementation of the SPAT was that several of the NASA organizations involved in software development were permitted to bypass participation.

The SPAT has been addressing a broad range of important software and process issues, including:

- software development processes
- software management processes
- training of developers and managers in software technology
- software acquisition processes
- the mandating of processes
- the role of a lead center in software management
- roles, responsibilities and reporting structure of the Software Working Group
- inclusion of people with a software background in the Systems Engineering Process Activity
- access to launch software of purchased launch vehicles in view of the Commercial Launch Act.

It is important that the SPAT focus on the level of recommendation that can lead to useful work and not get mired in excess detail. It is better to focus at this stage on what needs to be done rather than a formula for doing it.

The SPAT was charged with producing a comprehensive report after a small number of meetings. In retrospect, there may be too much in the task statement for the time allowed. NASA should ensure that computer software issues are given high priority throughout the agency and that those addressing these issues are given the support needed to produce adequate ways of dealing with them. The creation of the SPAT was an important initial step toward dealing with complex safety critical problems, but more needs to be done. In particular, all affected groups should be required to participate in these activities.

Ref: Finding # 31

There were several in-flight and ground-based episodes in which astronauts developed adverse reactions to substances used in human experiments. Although within the anticipated outcomes of the experiments, these events raise a concern with regard to the particular needs of protecting human subjects in a space flight environment. An aspect of the problem appears to be that there is insufficient independent oversight within NASA of the safety of human experiments. The researchers all submit their protocols to a standard Institutional Review Board (IRB) process. This is a good step, but it is a peer review and the IRB members may not necessarily be knowledgeable about the unique aspects of human experimentation aboard a spacecraft. Since NASA has the Office of Safety and Mission Assurance (OSMA) and it has responsibility for incident investigations, it would seem appropriate for OSMA to become involved in at least two areas related to human experimentation. First, OSMA could establish a review process to augment the standard IRB. Second, it could ensure that the Shuttle and Space Station systems requirements provide sufficient equipment, staffing and training to deal appropriately with any problems which might be experienced. Together with the standard IRB, the OSMA review would add significant breadth to the oversight of the safety of human experiments.

Ref: Finding #32

The ASAP has maintained a continuing interest in the Aviation Safety Reporting System (ASRS) since ASRS was established in 1975. In that year, the FAA asked NASA to develop and operate the system, acting as a neutral third-party between aviation operating personnel and the FAA. The ASRS was designed to receive voluntary reports of unsafe occurrences and hazardous situations, process, analyze, and interpret these reports, and disseminate findings and recommendations to the aviation community. The program is well managed.

extremely well-accepted by the aviation community, and the system has contributed to aviation safety by reporting insights and advisories that otherwise might be suppressed or lost through a highly-structured regulatory process. The value of the system has been confirmed repeatedly by operating and management personnel.

A recent report on the ASRS by a study team from the National Academy of Public Administration (NAPA) provided a thorough and complimentary review of ASRS (*A Review of the Aviation Safety Reporting System*, NAPA-August 1994). Given the many benefits of ASRS identified by NAPA, NASA and the FAA should restore the full capability of analysis, interpretation, and dissemination of the ASRS and promote electronic dissemination and expanded educational outreach.

Ref: Finding #33

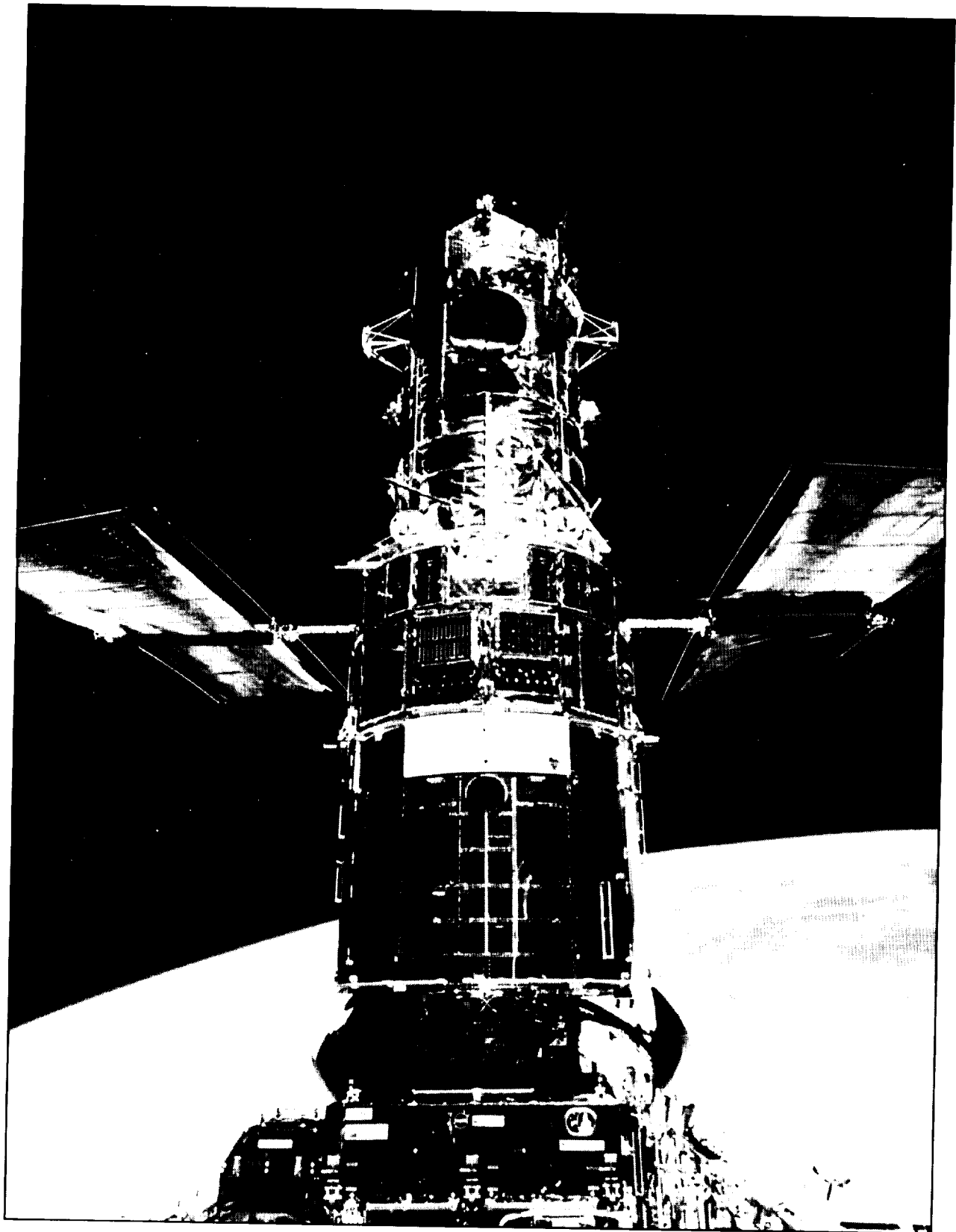
NASA's predecessor organization, the NACA, in establishing its research agenda, benefitted from the advice of experts drawn from industry,

the government and academia through an advisory committee structure. One such committee, the Committee on Aircraft Operations, provided advice in problem areas relating to meteorology, fire prevention, noise and flight safety. A similar panel was eliminated during a period when NASA was required to reduce the number of its advisory committees. This has created a void in the input NASA receives to define its aeronautical and flight safety research programs which should be filled. It may be possible to obtain the needed advice through the restructuring of the existing committee structure.

Ref: Finding #34

In previous reports, the Panel has questioned the commitment of the entire NASA/contractor team to the practice and principles of Total Quality Management (TQM). Whatever misgivings which may have once prevailed are now assuaged and the Panel is convinced that NASA and its contractors do, indeed, have TQM programs worthy of emulation by others both in and out of government.

IV. APPENDICES



APPENDIX A

NASA AEROSPACE SAFETY ADVISORY PANEL MEMBERSHIP

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Aerospace Consultant
Former Vice President, Engineering
Trans World Airlines

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Consultant, Former Senior Vice
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NASA Headquarters

MS. PATRICIA M. HARMAN
Staff Assistant
NASA Headquarters

APPENDIX B

NASA RESPONSE TO MARCH 1994 ANNUAL REPORT

SUMMARY

NASA responded on July 1, 1994 to the "Findings and Recommendations" from the March 1994 Annual Report. NASA's response to each report item was categorized by the Panel as "open, continuing, or closed." Open items are those on which the Panel differs with the NASA response in one or more respects. They are typically addressed by a new finding and recommendation in this report. Continuing items involve concerns that are an inherent part of NASA operations or have not progressed sufficiently to permit a final determination by the Panel. These will remain a focus of the Panel's activities during the next year. Items considered answered adequately are deemed closed.

Based on the Panel's review of the NASA response and the information gathered during the 1994 period, the Panel considers that the following is the status of the recommendations made in the 1994 Report.

	RECOMMENDATION	
NUMBER	SUBJECT	STATUS
1	U.S. and Russian Space Program safety concerns	CONTINUING
2	Impact of space debris on long-duration missions	CONTINUING
3	Space Station structural dynamics in collision-avoidance maneuvering	CONTINUING
4	Space Station Crew Rescue	CONTINUING
5	KSC Continuous Improvement	CLOSED
6	Impact on safety as a result of cost reductions at KSC	CONTINUING
7	KSC Space Shuttle processing problems due to human factors	CLOSED
8	KSC Structured Surveillance Program	CLOSED
9	Thermal damage to OV-103 elevon tiles	CLOSED
10	Development of improved tiles	CLOSED
11	Multipurpose Electronic Display System	CONTINUING
12	Improved Auxiliary Power Unit	CLOSED
13	Autoland	OPEN
14	Space Shuttle Main Engines (SSME)	CLOSED
15	High Pressure Fuel Turbopump (HPFTP)	CLOSED
16	SSME Block II development	CLOSED
17	Engine Sensors	CONTINUING
18	SSME health monitoring system	CONTINUING
19	Solid Rocket Motor Aft Skirt Stress	CONTINUING
20	Redesigned Solid Rocket Motor (RSRM) forward casing crack	CLOSED
21	Use of Advanced Solid Rocket Motor design features in the RSRM	CLOSED
22	Monitoring chamber pressure in RSRMs	CLOSED
23	Super Light Weight External Tank	CONTINUING
24	Integrated Logistics Panel Support to entire logistics program	CLOSED
25	Vision 2000 effects on logistics program	CLOSED
26	Just-In-Time manufacturing and shelf stocking concept	CLOSED
27	Main logistics system performance	CLOSED
28	Dryden Flight Research Center (DFRC) range safety policy and system	CLOSED
29	DFRC Flight Safety and Mission Assurance Organization	CLOSED
30	X-31 aircraft stability	CLOSED
31	Agencywide policy and process for software	CONTINUING
32	Space Human Factors Engineering Program	CONTINUING
33	Total Quality Management principles and practices	CLOSED

National Aeronautics and
Space Administration
Office of the Administrator
Washington, DC 20546-0001



JUL 1 1994

Mr. Norman R. Parmet
Chairman
Aerospace Safety Advisory Panel
5907 Sunrise Drive
Fairway, KS 66205

Dear Mr. Parmet:

In accordance with your introductory letter to the March 1994 Aerospace Safety Advisory Panel (ASAP) Annual Report, enclosed is NASA's detailed response to Section II, "Findings and Recommendations."

The ASAP's commitment to assist NASA in maintaining the highest possible safety standards is commendable. Your recommendations play an important rôle in risk reduction in NASA programs and are greatly appreciated.

We thank you and your Panel members for your valuable contributions. ASAP recommendations are highly regarded and receive the full attention of NASA senior management. We look forward to working with you.

Sincerely,

A handwritten signature in black ink, reading "Daniel S. Goldin". The signature is fluid and cursive, with the first name "Daniel" and last name "Goldin" clearly distinguishable.

Daniel S. Goldin
Administrator

Enclosure

1994 AEROSPACE SAFETY ADVISORY PANEL REPORT FINDINGS AND RECOMMENDATIONS

A. SPACE STATION PROGRAM

Finding #1: Joint U.S. and Russian space programs, including the Space Station, are now underway. Potential safety concerns arising from these collaborative efforts have not yet been completely defined or addressed.

Recommendation #1: Safety requirements for the joint programs should be established from a thorough understanding of the underlying policies of design, test, and review in use by each country. Timely total systems analyses should be conducted to ensure adequate safety of components and interfaces as well as overall system safety.

NASA Response: Safety concerns will be addressed by obtaining agreement from both NASA and the Russian Space Agency (RSA) on a common set of technical safety requirements and a review process.

The technical safety requirements for the Russian Segment Specification are intended to be the same as those being imposed on the other international partners. Of the 122 identified safety requirements, 92 have agreement, 15 have pending agreement, and 15 are still under negotiation. Presently, the Russians do not implement a safety review process similar to NASA's. The NASA safety review process is based on hazards analyses at the subsystem, system, and integrated levels. The closest equivalent in the Russian process is a review of "off-nominal" situations. Negotiations are in process to evaluate the Russian off-nominal situation process for compatibility with hazards analyses and to ensure that appropriate steps are implemented to address hazards with Russian hardware. The latest draft of the NASA/Russian memorandum of understanding provides for a NASA/Russian safety review process in Article 10, Safety and Mission Assurance.

Finding #2: Much good work has been done to assess the impact of space debris on the long-duration mission of the Space Station, and significant accomplishments have been made in developing shielding to protect the Station. However, there is still insufficient information on the probability that penetrations will have a catastrophic effect.

Recommendation #2: To support effective risk management, NASA should continue its emphasis on space debris problems, including a better characterization of the risk of catastrophic failures and an assessment of the capability to add shielding on orbit.

NASA Response: The international Space Station program is continuing to place strong emphasis on understanding, characterizing, and mitigating the risks associated with meteoroids and orbital debris. A Meteoroid/Debris Analysis and Integration Team (M/D AIT) consisting of NASA, contractor, and international partner technical experts is active and reports directly to the Vehicle Analysis and Integration Team.

The M/D AIT comprehensive strategy for managing M/D risks consists of a three-part approach; protection, avoidance, and risk abatement. Protection systems (state-of-the-art shielding) are baselined to prevent penetrations of critical elements for particles that are sized less than 1 cm. Collision-avoidance procedures will be implemented to protect the Station from the threat of larger, (typically greater than 10 cm) ground-trackable particles. The midrange size particles will be handled by a series of risk-abatement approaches that will be established initially and evaluated continually. These approaches are being pursued to characterize the risks of impacts of midrange (1 to 10 cm) particles and to increase the effectiveness of the protection offered by shielding and collision avoidance.

Risk abatement approaches with the goal of increasing protection system performance under consideration include: reduction of environmental model uncertainties, enhanced hypervelocity test and penetration analysis techniques, on-orbit shield augmentation capabilities, and alternate altitude strategies. Approaches that may increase collision avoidance effectiveness include enhanced radar capabilities and flight operations techniques. Finally, approaches being pursued to characterize and minimize the residual risks include; definition and assessment of critical items and the probability of catastrophic failures, advanced analysis of critical crack and fracture mechanics, crew training and operations techniques, and repair and replacement procedures.

Finding #3: Consideration is being given to maneuvering the Space Station to avoid larger debris that are capable of being tracked. Such maneuvers raise concerns about Station structural dynamics, disruption of the microgravity environment, and the ability of existing or planned systems to provide adequate debris tracking data.

Recommendation #3: Before adopting any maneuvering option, care must be taken to ensure that the dynamics of operation, including their effects on hardware, e.g., solar and radiator panels, and their influence on microgravity experiment operations, are considered. Realistic evaluation must also be made of the ability of ground-based and on-orbit systems to support maneuvering options with adequate debris tracking.

NASA Response: A collision-avoidance maneuver is, in practice, the same as a reboost maneuver. There are no concerns related exclusively to a reboost maneuver due to structural dynamic effects since all Space Station systems are being designed to handle a reboost; therefore, a known collision-avoidance maneuver will, likewise, present no structural problems.

However, a short-notice collision-avoidance maneuver could require a maneuver without being in the preferred configuration (i.e., solar panels, remote manipulator system). The operational procedures to ensure structural integrity and afford the capability for collision-avoidance on short notice continue to be worked.

The microgravity (micro-g) environment would be interrupted during an avoidance maneuver. However, the Space Station is not always required to be in a microgravity environment. The current microgravity requirement is for 180 days/year, subdivided into no less than 30-day periods. Current analysis shows that the Space Station could actually

exceed the requirement by two additional 30-day periods. Therefore, if a maneuver must occur, and a micro-g period is disrupted, the margin of two micro-g periods can be used for "recovery."

Ground-based tracking of space debris is provided by the U.S. Space Command, not NASA. Their systems have the ability to track debris particles as small as approximately 10 cm.

Finding #4: Present plans for rescue of Space Station personnel are not fully defined and may prove unsatisfactory without more precise and detailed planning, including necessary training and restrictions on the Station population.

Recommendation #4: NASA should reexamine current plans to ensure that they meet the required safety criteria. If they do not, priority should be given to the protocols necessary to ensure rescue of the entire Station crew if the Station must be evacuated.

NASA Response: The Space Station program is planning for the rescue of the entire crew in case of medical emergencies, Space Station evacuation, or interruption in Shuttle operations. Currently, the Space Station program plans to use Russian Soyuz spacecraft to perform this function during the assembly phase. This spacecraft has been proven over many years in supporting the Mir station. American astronauts will be fully trained in the use of Soyuz, and restrictions on its use by our astronauts are fully understood. Replacement of the Soyuz after the year 2002 is being considered by either a modified Soyuz or an American-built Crew Transfer Vehicle.

B. SPACE SHUTTLE PROGRAM

LAUNCH AND LANDING

Finding #5: The organization and management of Space Shuttle launch operations at Kennedy Space Center (KSC) continue to benefit from a "continuous improvement process" managed by the Shuttle Processing Contractor (SPC). Greater employee involvement, better communications, strengthened employee training and the use of task teams, process improvement teams, and a management steering committee have been major factors in this improvement.

Recommendation #5: A strong commitment to achieving "continuous improvement," despite budget cutbacks, should be maintained, at the same time recognizing the paramount priority of safety.

NASA Response: The SPC continues its deep commitment to Continuous Improvement (CI) with over 550 active process improvement teams and 86 percent of their 6,600-person workforce trained in the principles and precepts of CI. The underlying theme of all SPC initiatives is their pledge for the highest level of performance at the lowest possible cost with absolute dedication to safety and quality.

Finding #6: More than 1,200 positions have been eliminated by the SPC since September 1991 with only about 22 percent being achieved through involuntary separations. Present reductions have been achieved without an apparent adverse effect on the safety of launch processing. A comparable further reduction has been called for by the end of FY 1995. These additional reductions cannot likely be made without a higher probability of impacting safety.

Recommendation #6: KSC and SPC management must be vigilant and vocal in avoiding any unacceptable impacts on safety as a result of cost reductions planned for FY 1995 and beyond.

NASA Response: KSC and SPC management are firmly committed to the precept that safety will not be compromised as a result of cost reductions. Procedures for processing a safe space vehicle have been established and are strictly followed. These procedures are revised only after a thorough review by technical and safety personnel to ensure that safety will not be compromised. Schedule times are flexible; safety requirements are not. As the cost reductions continue, KSC is committed to processing only the number of vehicles that can be completed safely within available resources.

Finding #7: Several Space Shuttle processing problems at KSC have been attributed to human factors issues. KSC has recently formed a human factors task force to address these problems.

Recommendation #7: KSC should ensure that the human factors task force includes individuals with training and experience in the field. Specific assistance should be sought from appropriate research centers and technology groups within NASA.

NASA Response: The Management Steering Committee, chaired by the KSC Launch Director, established a CI team to support the Incident Error Review Board (IERB) in assessing human-error factors. This team reviewed the human-factors aspects of the Freon Coolant Loop Number 1 Pump Package incident on OV-105/STS-61 and made nine specific recommendations concerning the incident. A tenth recommendation addressed the need for the team to obtain training in human factors principles.

The CI Human Factors Team has since received training on human factors from the Battelle Memorial Institute in a seminar conducted at KSC. Some team members attended a class on incident investigation taught by The Central Florida Chapter of the National Safety Council. The team has subsequently added a new member with extensive experience in human factors from Analex Space Systems, Inc. The team will continue to pursue additional human factors training.

Finding #8: KSC has developed a Structured Surveillance Program with the objectives of decreasing overall process flow time, increasing "first-time quality," and reducing cost. The program approach involves reducing the reliance on inspections for assuring quality. Structured Surveillance also is proving valuable as a tool for the effective deployment of quality assurance resources.

Recommendation #8: The Structured Surveillance program should be continued and cautiously expanded.

NASA Response: KSC has improved structured surveillance data elements, data collection methods, and metrics for the entire program at KSC (both Government and contractor) and has discussed these improvements with the Panel. To ensure effective implementation of the Government application of the structured surveillance program, the leadership of this effort has been moved up to the directors of the two implementing organizations. These directors co-chair a newly formed control board that manages the generation and modification of the policies, procedures, and training necessary for full implementation of structured surveillance.

ORBITER

Finding #9: Thermal damage was noted on the STS-56 (OV-103) elevon tiles. The slumping of the tiles indicated that the tile surface reached a temperature of approximately 1,000° F. A temperature of this magnitude suggests that the temper and strength of the underlying aluminum structure could have been affected.

Recommendation #9: NASA should initiate an analysis to determine the temperature profile of the underlying aluminum structure of the elevons and its possible consequences on the strength of the Orbiter structure.

NASA Response: On STS-56 (OV-103), an alternate forward elevon schedule (part of Center of Gravity Expansion Activities, Detailed Test Objective (DTO) 251) was flown. This was the maximum-up schedule (12 degrees up) ever flown. There was some tile slumping (caused by temperatures exceeding 1500 degrees F) at the center hinge location, but detailed postflight vehicle inspection confirmed that the aluminum structure was neither damaged nor subjected to unacceptable temperatures. Positive Margins-of-Safety have been verified subsequently through thermal design analysis. A redesign has been certified and is currently being installed on all four vehicles. This new design will allow a full-up (16 degrees) elevon without overheating of the underlying structure. Prior to incorporation of this modification, the elevon schedule had been constrained to 7 degrees up.

Finding #10: The Shuttle tiles have provided effective heat protection. However, the surface of the tiles is easily damaged and their shrinkage and distortion properties are not as low as desired. A new tile formulation with superior characteristics and possibly lower density is being explored.

Recommendation #10: NASA is encouraged to support the development of thermal protection tiles with improved mechanical properties and lower density than the current Shuttle tiles.

NASA Response: NASA is considering several improvements to the Tile Protective System (TPS). On STS-51 (OV-105), a tougher tile coating on Fiber Reinforced Composite Insulation (FRCI-12) tiles was flown as a DTO on a few door tiles on the base heatshield. There were no hits on these tiles. However, the DTO will be flown a number of times to obtain a good evaluation of the improvement expected from this coating. This tougher coating will enhance turnaround activities by minimizing tile replacement due to coating damage.

Finding #11: NASA has made excellent progress on the engineering of the Multipurpose Electronic Display System (MEDS) for retrofitting Orbiter displays. However, there is no formal program to identify and include the safety advantages possible from a fully exploited MEDS.

Recommendation #11: A thorough review of the performance and safety improvements possible from a completely developed MEDS should be conducted based on crew inputs to system designers and researchers. A definitive plan should be developed to determine the schedule/cost implications of such improvements, and, if warranted, implementation should be scheduled as soon as possible.

NASA Response: The MEDS, when operational, will provide a foundation for potential upgrades and enhancements to the current crew displays that will improve safety. The initial MEDS program must be on line in a timely manner to replace aging electro-mechanical devices. The flight crew, mission operations, engineering, training, and safety, reliability, and quality assurance program personnel have all agreed that the "transparency" achieved by designing enhanced displays similar in function and appearance to the current displays is the optimum solution initially. By designing similar

but enhanced displays, the impacts for a mixed fleet while MEDS is being installed are minimized in the areas of training and flight software. There is only one single-motion base simulator, therefore, crews training for MEDS or non-MEDS equipped vehicles will be able to train on displays that are similar to those they will use in flight. Similar display formats do not require any changes to the existing flight software. Once trainers and laboratories are equipped with MEDS, the test beds will be in place to evaluate display upgrades.

The next phase of the total orbiter displays-and-controls update activities will be to achieve a world-class state-of-the-art system by expanding the total complement to digital electronics replacing current wiring and switches as practical. Planning for this phase is beginning, but the exact implementation schedule will be dependent on funding availability as well as future human-tended spacecraft planning.

Finding #12: The Improved Auxiliary Power Unit (IAPU) has experienced problems that have impacted Space Shuttle processing and logistics.

Recommendation #12: A new focus on increasing the reliability of the total IAPU system should be initiated and supported until the identified problems are solved.

NASA Response: To improve Auxiliary Power Unit (APU) reliability, a continuous improvement program has been underway since the STS 51-L accident. Results from this program include the completion of an IAPU "upgrade" project (which eliminated injector tube corrosion, exhaust housing cracking, and some Criticality 1 concerns), a new design for the turbine wheel, an improved APU controller and fuel isolation valve, and the more reliable "Path a" Gas Generator Valve Module (GGVM). These changes have resulted in a greatly reduced rate of APU in-flight anomalies and fewer delays to the Shuttle processing and logistics support activities. Elements of the continuous improvement program not yet complete, but now underway include development of an entirely new GGVM, certification of a new material for the fuel pump thermal isolator, and development of more vibration-resistant thermostats. As the new GGVM is incorporated in the fleet, the APU should be totally certified for its planned 75-hour life capability.

Finding #13: In its response to the Panel's last Annual Report, NASA indicated that "The program is reviewing the operational flight rules pertaining to Autoland, we have budgeted upgrades in software and hardware to improve the Autoland functionality, the life sciences organization is collecting physiological data and developing countermeasures to ensure adequate crew performance as the mission duration increases. We are confident with using Autoland in a contingency mode, but do not plan to demonstrate Autoland until a firm requirement mandates a demonstration."

Recommendation #13: The focus of Autoland should not be exclusively on long-duration missions. NASA should formulate a complete set of operational procedures needed for emergency use of Autoland, taking into account a full range of operational scenarios and equipment modifications that might be beneficial. These include upgrades to the

Microwave Scanning Beam Landing System (MSBLS) receiver group, and installation and certification of Global Positioning System (GPS) capability.

NASA Response: It is agreed that the Autoland system should not be focused just on long-duration missions. Currently, mission planning requirements do not include missions longer than approximately 18 days, including the Space Station program. The entry systems requirements including piloting techniques are continuously assessed for improvements. Autoland backup capabilities as well as heading alignment cone piloting enhancements are being developed and will be incorporated as we continue to implement the flight program. MSBLS/GPS type systems are being considered and will be brought on line as improvements are practical.

No specific training or procedures are required for the emergency use of Autoland, as the only manual tasks required of the crew in an Autoland scenario (e.g., deploying landing gear, postlanding braking, air data probe deployment, and navigation sensor data incorporation) are identical to those performed in a manual landing. Present flight rules define orbiter and landing-site equipment that must be functioning to perform an Autoland landing. The decision to engage Autoland in a contingency is left to the commander's discretion to protect the safety of the crew. Exact flight rules to define all Autoland engagement criteria exceed the number of failure cases addressed by the current flight rules. A program to expand these criteria would require large resource commitments to develop and is not currently in the planning.

SPACE SHUTTLE MAIN ENGINES (SSME)

Finding #14: The SSME has performed well in flight but has been the cause of launch delays and on-pad launch aborts that were primarily attributable to manufacturing control problems.

Recommendation #14: Continue to implement the corrective actions developed by the NASA and Rocketdyne manufacturing process review teams and devise techniques for detecting and/or precluding recurrence of the types of problems identified.

NASA Response: The process audit teams and the NASA and Rocketdyne incident investigation teams have both identified process improvements which either have been or will be incorporated into all areas of the engine program. These process improvements will improve detection and preclude the recurrence of manufacturing control problems in any of our new or recycled hardware and substantially reduce the likelihood of associated problems leading to launch delays or launch pad aborts.

Finding #15: "Sheetmetal" cracks in the Phase II (current) High Pressure Fuel Turbopump (HPFTP) have become more frequent and are larger than previously experienced. This has led to the imposition of a 4,250-second operating time limit and a reduction of allowable crack size by a factor of four. Congress has delayed the funding for restarting the development of the alternate HPFTP. This new turbopump design should eliminate the cracking problem.

Recommendation #15: Restart the development and certification of the alternate HPFTP immediately.

NASA Response: NASA fully agrees with the recommendation to restart the alternate HPFTP immediately. Congressional authority to restart the program was received on April 14, 1994. The Space Shuttle program (SSP) is proceeding with the restart. The alternate HPFTP will be incorporated into the Block II SSME configuration with first flight scheduled for September 1997.

Finding #16: The approved parts of the engine component improvement programs, now organized into block changes, are progressing well. The Block I grouping will enter formal certification testing by mid-1994. Progress in the Block II effort is, however, hampered by the delay in restarting the alternate HPFTP development effort.

Recommendation #16: Continue efforts to complete *all* of the Block II development as soon as possible.

NASA Response: NASA fully agrees with this recommendation and is firmly committed to developing and implementing all of the SSME safety improvements, including the Alternate HPFTP and the Large Throat Main Combustion Chamber. Upon completion of these modifications, a significant reduction in Shuttle operational risk will be realized. Initiation of full-scale development testing is currently planned for mid-1995, with first-flight capability scheduled for September 1997.

Finding #17: Engine sensor failures have become more frequent and are a source of increased risk of launch delays, on-pad aborts, or potential unwarranted engine shutdown in flight.

Recommendation #17: Undertake a program to secure or develop and certify improved, more reliable engine condition sensors.

NASA Response: Improved hot gas temperature-sensing instrumentation is undergoing development testing and is planned for the first flight in FY 1995. A two-step improvement process for pressure and flow measuring instrumentation is also under way. As a first step, a new screening selection process has been developed for immediate implementation to improve sensor quality control. The second step, redesigning and improving sensors, is being implemented as these improvements become available.

Finding #18: The SSME health monitoring system comprising the engine controller and its algorithms, software, and sensors is old technology. The controller's limited computational capacity precludes incorporation of more state-of-the-art algorithms and decision rules. As a result, the probabilities of either shutting down a healthy engine or failing to detect an engine anomaly are higher than necessary.

Recommendation #18: The SSME program should undertake a comprehensive effort to improve the capability and reliability of the SSME health monitoring system. Such a

program should include not only improved sensors but also a more capable controller and advanced algorithms.

NASA Response: NASA agrees that the development and implementation of an advanced health monitoring system for the SSME is potentially worth pursuing. A system currently being considered would incorporate more processing capability in an upgraded controller and allow the utilization of advanced health monitoring software algorithms. With an improved system of this nature, the probability of shutting down a healthy engine would be reduced while the probability of preventing a catastrophic failure would be increased. NASA is reviewing proposals that would certify and implement this new capability into the Block II SSME configuration.

SOLID ROCKET MOTORS

Finding #19: A segment of an aft skirt will be used to test the effectiveness of an external bracket modification in reducing the overall bending stress of the skirt. The validity of using an 11-inch-wide test specimen to determine the effectiveness of the bracket is yet to be demonstrated.

Recommendation #19: NASA should evaluate the first specimen test results to see if the strains in the weld area duplicate the strains found when a full aft skirt was tested in the Static Test Article-3 (STA-3) test. If not, another test approach should be pursued.

NASA Response: Tests on three of the four aft skirt test specimens have been completed. The baseline test article (TA-1), which represents the current aft skirt configuration, has been subjected to 100 percent of the developed load case. Based on a thorough evaluation of the TA-1 test data and correlation of the data with STA-3 test results, it is clear that the weld area strain field developed in the TA-1 test article correlates well with the strain field in this same area on the STA-3 aft skirt. This correlation confirms the validity of the test approach being used.

The second test article (TA-4) was also in the baseline configuration and was subjected to a maximum load of 70 percent of the developed load case. This article utilized the photoelastic method for determining the strain field as opposed to using the typical strain gage method used on all other articles in this test program. This test verified that the STA-3 strain field could be duplicated on two separate articles within acceptable limits and that no high strain areas were overlooked during the analytical study of the test article response.

The third test article (TA-2), which has an external bracket for the reduction of strain in critical weld region, was subjected to 205 percent of the developed load case with no structural anomalies occurring. Comparisons of the baseline configuration article (TA-1) and the bracketed configuration article (TA-2) were made at 100 percent loads. This comparison demonstrated that there was approximately a 50 percent reduction in the average weld strain in the critical weld region.

The baseline configuration article (TA-1) was tested to failure during June 1994. This test defined the weld failure strain for the TA-1 article. Test data obtained from this test is being compared to the results of the 205 percent TA-2 test and the STA-3 test to develop a comparative assessment of the benefit gained by the addition of the external bracket modification. If this assessment does not reveal adequate stress reduction, additional testing may be indicated.

Finding #20: A small crack was found in the inner wall of a forward Redesigned Solid Rocket Motor (RSRM) casing used for STS-54. Although slightly above the specified minimum detectable size, it was well within the acceptable limits for safe flight. This was the first time that a crack had been found in a forward segment, although cracks have previously been detected in other segments. The crack occurred during the manufacturing heat treatment process because of an inclusion in the parent material.

Recommendation #20: The X-ray and magnetic particle inspection program criteria should be re-evaluated to assess their ability to detect cracks of the size found.

NASA Response: A single crack was detected during standard refurbishment of the forward segment flown on STS-54. The subsequent investigation determined that an inclusion introduced into the metal during the manufacturing process caused the crack to form during heat treatment of the cylinder. The segment had been flown four times prior to detection of the crack. Prior to each of these flights, the cylinder was proof tested, which demonstrated safe life (4 mission cycles) in the membrane region where this crack was found.

All areas of the RSRM metal hardware (case, nozzle, igniter) have been reevaluated with respect to critical flaw size and whether proof test, magnetic particle inspection or other nondestructive evaluation methods are required to demonstrate compliance to safe life requirements. As a part of this reevaluation, an RSRM hardware configuration specific magnetic particle inspection probability of detection (POD) study was completed. Prior to this study, crack detection threshold limits were based on industry standards. This RSRM magnetic particle inspection POD study incorporated RSRM specific geometries, physical access, gauss levels, surface finishes, potential flaw types, inspection times, and multiple operators. The results demonstrated that, in the areas of the RSRM hardware upon which magnetic particle inspection is solely relies, the detectable flaw size is smaller than the critical flaw size. Proof test is the method of choice used to demonstrate safe life in the case membrane region, not magnetic particle inspection.

X-ray inspection is not used for crack detection in RSRM metal hardware. Magnetic particle inspection capability has been reevaluated and, as a result of an RSRM hardware configuration specific POD study, detection capability versus location is well characterized. In those areas that rely solely on magnetic particle inspection, the detectable flaw size is smaller than the critical flaw size.

Finding #21: The Advanced Solid Rocket Motor (ASRM) project has been canceled. Some elements from the ASRM development have possible reliability and/or performance benefits if they were applied to the RSRM.

Recommendation #21: Examine the potential applicability and cost-effectiveness of including selected ASRM design features in the RSRM.

NASA Response: The RSRM project has continued to consider ASRM design attributes, as motivated by RSRM flight results, performance goals, obsolescence issues, and cost enhancements. Examples of these are the RSRM project's ongoing initiative to replace metal parts vapor degrease cleaning with an aqueous process and the ongoing initiative to remove asbestos from the primary RSRM insulation material. Both of these obsolescence replacement activities have drawn from previous ASRM activity.

There are numerous ASRM design attributes for potential consideration for future adoption in the RSRM. These include, in part, propellant formulation (hydroxyl-terminated polybutadiene), sealing system designs, pressure vessel design and materials, some attributes of the nozzle design, and some manufacturing process automation, such as insulation strip winding and Real Time Radiography (RTR) for nozzle and case inspections. At present, the RSRM project is considering incorporation of the previous ASRM RTR system into the RSRM hardware verification process and the use of ASRM manufacturing equipment for nozzle fabrication. Based on collective consideration of the implementation cost impacts and RSRM flight demonstrated hardware performance, no requirements have been established to pursue the ASRM sealing system, pressure vessel, or nozzle design attributes. However, future justifications in these areas are possible based on continuing RSRM flight evaluation or increased Shuttle program performance requirements.

Finding #22: A chamber pressure excursion of 13 psi (equivalent to a thrust perturbation of 54,000 pounds) occurred in one of the RSRMs of STS-54 at 67 seconds of motor operation. A thorough investigation of the phenomenon was initiated and found that the most probable cause was the expulsion of a "slug" of liquid slag (aluminum oxide) generated during normal propellant combustion. Analyses showed that, even under statistical worst-case conditions, the safety of the Shuttle system is not compromised by such perturbations. Some testing and analyses are still scheduled to complete the investigation.

Recommendation #22: Complete and document the investigation, and continue the established practice of monitoring chamber pressures and examining possible remedial actions.

NASA Response: The RSRM project has concluded its investigation and has determined that the generic cause of chamber pressure excursions is the periodic expulsion of liquid slag (aluminum oxide). Slag is produced during normal propellant combustion and is temporarily accumulated in the aft end of the nozzle prior to being "dumped" through the nozzle. The RSRM project has implemented the recommendations set forth by the Panel and has established a program to continue to evaluate multiple parameters that could affect the pressure perturbations. The results and findings of these studies are being reviewed and changes to the processes or specification will be made if it is concluded that they will be beneficial to the program.

A very detailed study of many process and material parameters that influence slag formation has been conducted to determine if a statistical correlation exists between these parameters and the pressure perturbations. Examples of these parameters include humidity, time in process, ammonium perchlorate (AP) moisture content, mix times, cast times, viscosity, mechanical properties, and many others. No special causes or process deviations related to pressure perturbations have been identified. Analyses have shown that, under the worst case conditions, the safety of the Shuttle system is not compromised by the pressure phenomenon. The results of this extensive study are currently being documented by Thiokol.

Chamber pressures are being analyzed or monitored by Statistical Process Control charts. Eighteen acceptance tests are conducted for each lot of AP. The flight and static test pressure perturbation history is reviewed before every launch. Additionally, several other studies are being conducted to improve the predictability of pressure excursions. Quench bomb tests recorded with high-speed film have been used to identify burn-rate differences in the various propellant mixes. Five-inch diameter spin motor tests are being conducted to evaluate the amount of slag that is generated in a motor. This testing employs a design of experiments to evaluate the effects of ground AP, unground AP, differences in AP vendors, aluminum-particle sizes and vendor differences, particle-size distributions, iron oxide surface area, and several other parameters.

EXTERNAL TANK

Finding #23: A Super Light Weight External Tank (SLWT) has been proposed as a means of increasing the payload performance of the Space Shuttle. The tank would employ structural changes and be made from an Aluminum-Lithium (Al-Li) alloy. The SLWT appears to involve no safety decrement and low technical risk.

Recommendation #23: The impact of the SLWT on the total system should be carefully examined.

NASA Response: The External Tank Project and Shuttle program are thoroughly committed to an integrated system approach to the design and development of the SLWT. A systems integration plan to ensure the timely assessment of SLWT effects on the Shuttle system, and to ensure programwide-managed implementation is currently in development.

LOGISTICS AND SUPPORT

Finding #24: The Integrated Logistics Panel (ILP), which meets at 6-month intervals to report and coordinate the activities of the NASA Centers and their contractors, is performing a vital service in helping to control the entire Space Shuttle logistics program.

Recommendation #24: The ILP should continue to be supported as an effective means of maintaining control and coordination of the entire logistics program.

NASA Response: NASA Centers and contractors continue to support the ILP and related integration activities. All project elements benefit from the exchange of technical data presented at ILP meetings. NSTS 07700, Volume XII, "Integrated Logistics Requirements", the program's requirements for integrated logistics was recently updated, and the ILP provided a focus for this effort. The ILP will continue to serve as the forum for problem solving, technical information exchange, and the appropriate level of control, coordination, and integration of Shuttle logistics support.

Finding #25: The *Vision 2000* cost-reduction program promulgated in May 1993 includes some major changes in the logistics and support areas.

Recommendation #25: All changes that might impair logistics and support functions in the name of cost-cutting should be most carefully reviewed before implementation.

NASA Response: As the program continues to plan for the future, the *Vision 2000* approach to the program will remain relevant. The *Vision 2000* approach is based on the following two principles: operate within SSP experience and locate decisionmaking near operations. Notwithstanding the advantages these principles offer to the current Shuttle logistics community, the SSP office will remain vigilant and exercise caution when making cost-cutting decisions and changes necessitated by funding reductions.

Finding #26: Introduction of the Just-In-Time (JIT) manufacturing and shelf-stocking concept by NASA logistics at KSC is a potentially effective method of cost control.

Recommendation #26: JIT should be used with caution and with a thorough understanding of how it may impact the availability of Space Shuttle spares and hardware supplies.

NASA Response: All projects have cautiously considered the JIT method of spares provisioning and are in different stages of planning and implementation. Launch and Landing Project (L&L) has applied the JIT method to manufacturing activity. In addition, L&L is further studying alternative methods of prioritizing repair work which may be applied to JIT repairs at a later date. Operational availability will be uppermost in any JIT implementation decision strategy affecting spares and hardware supplies.

Finding #27: A review of the main logistics system performance parameters indicates that the program is generally performing effectively. There are minor problems with zero balances, and repair turnaround times appear to be worsening. Cannibalization, with the exception of the IAPU, is at a minimum. Because of manufacturing and assembly quality problems, the number of spare engines is at a minimum and could become a logistics problem.

Recommendation #27: Additional emphasis should be focused on repair turnaround time improvement and the reduction of cannibalization of SSME and IAPU components. NASA should continue the efforts to improve SSME manufacturing control and quality processes to preclude future engine availability problems.

NASA Response: Supportability indicators for improved performance are continually monitored. Increased coordination with vendors, transition of selected tasks from vendors, and resolution of technical issues related to higher-than-normal hardware failure rates have assisted in expediting hardware delivery. The average repair turnaround time for L&L is 25 percent lower than FY 1988, but supportability is the key measurement of logistics success. Items that are not needed to ensure support (on either a vehicle or the shelf) are no longer being repaired on a priority basis to save dollars. Minor problems associated with zero balances should improve through the identification of single-source vendors and continued efforts to identify alternate sources.

IAPU's continue to be worked on a priority basis. Most of the technical problems associated with cannibalization in 1993 have been solved. There was no cannibalization during the period January through April 1994, as there are spare units at KSC. In addition, ongoing discussions with vendors are attempting to improve production issues, and a redesign is underway as a long-term solution. Monitoring of this critical asset will continue.

The SSME Project Office encountered a short-term issue with contamination of temperature transducer probes. Plans for resolution of this issue include process changes and testing (green run) prior to delivery to L&L. Pump and nozzle shortages are the result of natural disaster (Northridge earthquake), other technical issues, and the SSME project standdown period. Full implementation of changes in methods of support to manufacturing control and quality processes should improve availability of SSME hardware. We will intensively manage the correction of these issues to ensure availability of complex SSME hardware.

C. AERONAUTICS

Finding #28: The Dryden Flight Research Facility (DFRF) does not presently have a range safety policy and system for Unmanned Aerial Vehicles (UAVs) such as the Perseus, which is about to enter extensive testing. A working group under the DFRF Chief Engineer is examining the issue.

Recommendation #28: DFRF should develop a range safety policy and system that are adequate to cover its contemplated UAV projects.

NASA Response: The Director of the Dryden Flight Research Center (DFRC), *nee* Dryden Flight Research Facility (DFRF), has recently established a policy document on UAV flight operations and activities. This policy has been coordinated closely with Edwards Air Force Flight Test Center (AFFTC) officials, since air space and facilities are managed by the local Air Force establishment.

The Perseus UAV, having just completed its initial contracted flight test activity, during which it achieved an altitude of 16,500 feet, is being operated in accordance with this policy. It is our intent to continue using the Perseus vehicle as a pathfinder for validation of UAV operational procedures during step-by-step expansion of the flight envelopes for expanding the flight altitude up to 85,000 feet. DFRC will continue to assure safe flight operations and control of UAV flight activities through technical risk analysis, management reviews, and the imposition of appropriate range safety precautions prior to each flight.

Finding #29: The DFRF flight safety and mission assurance organization now reports directly to the Director of the facility.

Recommendation #29: None.

NASA Response: This change in reporting authority will continue to ensure that flight safety and mission assurance issues are addressed in a timely manner and to the appropriate level of Center management.

Finding #30: The X-31 aircraft exhibited some undesirable stability characteristics at higher subsonic speeds and an unexpected departure during a high angle of attack test. It also carries an insufficient quantity of hydrazine to run its emergency power unit long enough to return to the Edwards runway from the typically used flight test site.

Recommendation #30: Future test objectives for the X-31 should be based on an assessment of the specific program objectives that can only be uniquely and safely performed by this aircraft.

NASA Response: The X-31 has no undesirable stability characteristics at higher subsonic speeds within its current cleared flight envelope. There is, however, a pitch-up tendency between 0.91 and 0.95 Mach number when the aircraft is between 10 degrees and

12 degrees angle of attack (AoA). This represents flight at elevated gravitational (g) loading (2.5g to 4.5g, depending on altitude) outside of the 0.9 Mach number envelope limit. The condition is caused by a positive (nose up) break in the airframe pitching moment. It was predicted by wind tunnel tests and was a known condition prior to being encountered in flight when the aircraft inadvertently exceeded the Mach limit during a wind-up turn.

To mitigate the risks associated with this characteristic, the X-31 now operates with the flight envelope restricted to 0.85 Mach number, except for planned test maneuvers. As an added precaution, the Master Caution/Warning (MCW) tone activates when the Mach number exceeds 0.88 and a caution light is illuminated in the cockpit. When specific tests, such as the supersonic quasi-tailless demonstration, require exceeding this Mach number, the air crew and engineering staff are briefed, an AoA limitation is enforced, and responsibilities for real-time monitoring are reviewed. The reduced Mach limit and other procedures have not affected achievement of the X-31's flight test goals. No subsequent pitch-up incidents have occurred since these procedures were emplaced.

The X-31 experienced a yawing departure very early in its poststall envelope expansion flight test program. The test, a split-s and pull to 60 degree AoA from 125 knots calibrated airspeed (KCAS) at 35,000 feet (about 1.3g's maximum), was only the third elevated g post-stall entry test and represented a modest step toward the goal of 0.7 Mach number post-stall entries. Both the pilot and the control room quickly recognized the departure and called for recovery according to the prebriefed monitoring procedures. The pilot was able to immediately pitch down to conventional AoA and recover the aircraft to controlled flight.

The departure was due to an unexpected aerodynamic asymmetry, but such occurrences were not unanticipated. The pitch recovery margin designed into the aircraft, the planned and gradual buildup of flight maneuvers and conditions, and the monitoring procedures ensure the maximum chance for safe recovery from this kind of unexpected problem.

Further, after the "departure," poststall flight-envelope expansion was suspended until the cause of the departure was identified, understood, and fixed. Wind tunnel tests indicated that the large aerodynamic yaw asymmetries that caused the departure were due to the very sharp nose of the X-31 aircraft. The asymmetries experienced during flight were more than five times as large as wind tunnel predictions, but it was discovered that the aircraft was built with a nose that was sharper than the wind tunnel models. The wind tunnel tests further suggested that a slight blunting of the aircraft nose to match the wind tunnel model would probably eliminate the problem and that small nose strakes would further improve the asymmetries and the directional stability of the aircraft at 60 degree AoA.

The aircraft was modified to blunt the nose and add the nose strakes. Maneuver and flight condition buildup was changed to increase in smaller steps. Monitoring procedures were reviewed (and subsequently adjusted), and the flight test expansion of the elevated-g, poststall entry and maneuver envelope resumed. Since then, no departures or

near-departures have occurred, and the aircraft has been cleared to poststall entries up to 265 KCAS or 0.7 Mach number (almost 6g's maximum) with unrestricted maneuvering up to 70 degrees AoA. These flight test operating modifications will enable the project to accomplish its tactical utility program objectives.

During the design, fabrication, and assembly of the X-31, Rockwell, MBB, and the Naval Air Systems Command were confronted with a number of difficult tradeoffs in attempting to achieve the desired thrust-to-weight ratio in the aircraft. One of the most deliberated issues was the purpose and function of the electrical power unit (EPU). As a result of these deliberations, the EPU was sized for the purpose of providing uninterrupted electrical and hydraulic power for enough time to restart the engine in the event of a engine flameout. The EPU was never intended nor, more importantly, designed to provide the capability to return to base.

The philosophy for the utilization of the EPU is consistent with other single engine aircraft (i.e., the X-29A and the F-16). The X-31 EPU run time is nominally 4.5 minutes, while the X-29A had 8.0 minutes and the F-16 has a minimum of 10.0 minutes. DFRC's current operating procedures do not recommend a dead-stick landing (neither did the X-29A's); however, it is a pilot option if the aircraft is close to a landing flight condition.

The ability to land "engine-out" is determined by both the EPU time and the flame-out landing distance of the aircraft. The flame-out landing distance is an imaginary inverted cone of distance versus altitude determined by the glide ratio of the aircraft. This cone may be further restricted in altitude and distance by EPU duration. Outside of this cone, no amount of EPU time will permit an "engine-out" landing. Much of the flight test site areas typically used at Edwards are beyond the flame-out landing range of any fighter aircraft. Flights at 10,000 feet, for example, would have to be performed within approximately 10 miles of Edwards to remain within this glide cone.

When the aircraft were moved to Dryden and NASA became an active member of the International Test Organization and assumed flight clearance authority, a complete independent review of the aircraft systems and issued flight clearance using the Dryden Basic Operations Manual was conducted. During the course of this review, DFRC focused on two major concerns--the potential for the engine to stall during high AoA testing and the quantity of hydrazine available for the EPU.

The potential for the engine to stall during high AoA was studied at the outset of flight test operations, as an undesired event, and was subsequently assigned the probability for occurrence as being unlikely (but possible), and the risk for potential loss of aircraft (with safe ejection of the pilot) was accepted. As the result of a more recent review of the accepted risks, the probability of occurrence was downgraded to *extremely improbable* based on the completion of high AoA envelope expansion and more than 170 hours of aggressive maneuvering performed during the tactical utility phase of the program with *no* engine anomalies or stalls experienced. Engine operation will continue to be monitored "real time" from start through shutdown, and any additional knowledge

obtained will modify our risk knowledge data base or, more importantly, it may form the basis for changes to mitigate risk.

To assess the potential impact due to the low quantity of hydrazine available for the EPU, Dryden performed a complete-risk analysis of the aircraft, including engine and subsystem reliability, proximity of flight operations to landing areas, and other pertinent factors. Based on this review, a hydrazine quantity gage was installed to give the pilot essential information on whether or not to remain with the aircraft in the event of a system failure. The gage quantity is checked as part of the aircraft preflight inspection and the hydrazine quantity is monitored "real time".

Based on our experience with the X-29A, we concluded that the philosophy embodied in the original design was reasonable, and the risk was acceptable if we instituted and maintained a closely managed quality control and maintenance inspection program. Therefore, Dryden management placed hydrazine quantity on the accepted risk list. We are managing risks that are entirely acceptable for this experimental aircraft program, sponsored by the Advanced Research Projects Agency (ARPA). This has been borne out by the successful completion of all program objectives to date.

Safety of the operation of the aircraft test vehicle and safety of the test points to be performed are continually reviewed and improved. The "unexpected departure during a high angle of attack test" is an excellent example of how an unexpected problem was dealt with and eliminated.

As a result of the extremely successful completion of the X-31 flight test program objectives, an 8-month follow-on program is being planned to explore in-flight virtual targeting development, assessment of high AoA/off boresight missiles, pseudo tailless aircraft flight tests, using thrust vectoring; and evaluation of high AoA handling qualities and design criteria, as evolutionary steps to the completed program. These programs will use the existing flight envelope and the same airspace used in the completed program. The only planned use of the supersonic corridor, which results in the greatest excursion from the Edwards Air Force Base airspace, is during a portion of the Agile Warrior virtual-adversary demonstration.

This high-priority Navy/ARPA-sponsored follow-on program takes advantage of the unique capabilities of the X-31 aircraft to begin pursuing these objectives immediately. These capabilities include providing support for existing research and laying the groundwork for follow-on efforts, such as the Joint Advanced Strike-Fighter Technology Program.

At the completion of the 8-month follow-on program, an assessment and review will evaluate the feasibility and risks associated with the reduction of vertical tail size as a further extension of the study of thrust vectored flight capability. Results from this assessment will be briefed to the Dryden Airworthiness Board as part of the new program proposal and appropriate action will be taken. The ASAP Chair will be invited to the Air Force Safety Review Board review of this subject.

The reduced tail size tests will use the X-31's mature simulation data base, its fully integrated thrust vectoring/flight control system, and the experience gained in the quasi-tailless tests to investigate tailless flight. This will provide valuable experience and data to support design drag, weight, and manufacturing savings to commercial and to military aircraft. Military aircraft would also benefit from the reduced-radar signature of these new designs.

The "Agile Warrior" program will integrate key enabling technologies, such as advanced pilot situational aids, helmet displays, cockpit displays, and a wide-area distributed simulation network, to create a realistic war fighting/training environment linking airborne aircraft with multiple ground-based simulators. This promises cost savings in both training and in rapid assessment of advanced technologies in a large-scale, realistic simulation environment.

Other tests investigate sensor design, maneuverability, agility, performance, and handling qualities during poststall maneuvering and in conventional flight using thrust vectoring. The valuable data from these envelope-expanding flight tests will enhance integration of these technologies into operational aircraft designs.

In conclusion, safety of flight for the X-31 International Test Organization has always been and will continue to remain our foremost guiding principal. The achievement of planned flight test objectives will continue to be guided by a methodical process of flight data evaluation and gradual, deliberate expansion of flight envelopes. Risks will be understood and prudently accepted with the safety of the pilot and aircraft as the principal considerations.

D. OTHER

Finding #31: NASA's past approach to software development has been to incorporate it within the individual programs, allowing them to determine their own requirements and development, verification, and validation procedures. In the future, as the complexity of NASA's computer systems and the need for interoperability grow, this mode of operation will be increasingly less satisfactory. While NASA has some good software practices, it does not have the overall management policies, procedures, or organizational structure to deal with these complex software issues.

Recommendation #31: NASA should proceed to develop and implement an Agencywide policy and process for software development, verification, validation, and safety as quickly as possible.

NASA Response: A software process action team, sanctioned by the Acting Deputy Administrator and the Information Resource Management Council, is working on Agency software issues including roles, responsibilities, standards, and procedures. The Office of Safety and Mission Assurance is leading the Agency in strategic planning for the Agencywide software program with a NASA working group consisting of members from Centers, industry, and academia.

A Software Safety Standard has been completed. Our present plan is to establish this as an interim standard for 1 year at which time it will become a mandatory requirement for newly developed software. The Software Independent Verification and Validation Facility will focus on the Agency software processes for development, verification, and validation in accordance with the Software Strategic plan currently being developed.

Finding #32: NASA has consolidated life and microgravity sciences and applications, including human factors in the Office of Life and Microgravity Sciences and Applications (Code U). A *Space Human Factors & Engineering Program Plan* is being prepared to guide future *research* activities. There remains, however, a clear need for more *operational* human factors input in both the Space Shuttle and Space Station programs.

Recommendation #32: The Program Plan should be expanded to include support of the operating space flight programs to ensure that sufficient human factors expertise is included.

NASA Response: The Life and Biomedical Sciences and Applications Division is committed to developing a new, dynamic Space Human Factors Engineering Program that will integrate human factors knowledge and methodologies into the Shuttle and Space Station programs. Leadership of this program resides within the Environmental Systems and Technology Branch of Code U, which is responsible for directing an integrated Space Human Factors Engineering research and development program. New processes and procedures will be developed to enhance crew training, augment the design of complex automated systems, and use extreme and isolated environments to conduct analog studies. Research programs will continue; however, the primary focus of

the program will shift from *knowledge acquisition to knowledge application*. This shift will extend human factors support to operational areas and emphasize the improvement of processes and products.

The Space Human Factors Engineering Program Plan, developed in 1993, is being revised to reflect this shift of emphasis, and an implementation plan will be developed to establish and maintain this new focus. Emphasis will be placed on identifying specific, adequate funding for meaningful results, and promoting the added value of human factors through concurrent engineering throughout the Agency. A Space Human Factors Engineering Customer Team, currently being established at Headquarters with representatives from Codes U, M, R, and Q, is being received in a spirit of cooperation and collaboration. These changes should create a safer and more productive operational environment for all flight and ground activities planned for current and future programs.

Finding #33: There are excellent examples of Total Quality Management (TQM) principles and practices in various contractor and NASA activities.

Recommendation #33: NASA and contractor management should use the existing *effective* TQM implementations as models for their continuing TQM efforts.

NASA Response: The Office of Continual Improvement is aggressively pursuing implementation of TQM across NASA. Particular emphasis has been focused on the Agency Quality Steering Team (QST) and Continual Improvement Council (CIC) activities. The Agency Continual Improvement Plan is in the final stages of development and is expected to be signed in late summer 1994 by the Chair of the QST (the Acting Deputy Administrator). In addition, the Office of Continual Improvement has worked with the Office of Human Resources and Education in developing and establishing training courses for enhancing individual expertise in applying TQM concepts. As an example, a 2-day Joiner Team Training session focusing on a common team framework for continual improvement teams was presented in May 1994 to the Headquarters CIC and others.

Although the Panel's report cites specific positive applications of TQM in providing an assessment of the NASA results, we recognize that continual improvement across the Agency and its contractors is necessary. We will continue to encourage and practice continual improvement in all areas to affect the necessary changes.

APPENDIX C

NASA AEROSPACE SAFETY ADVISORY PANEL ACTIVITIES JANUARY 1994 - JANUARY 1995

JANUARY

19 Total Quality Management Letter Report to Administrator

FEBRUARY

3 Congressional Staff Visit re Panel's Annual Report,
Washington, DC

15 Panel Review of NASA's Strategic Plan

23-25 Review of Multi-Function Electronic Display System/Pilot Assisted
Landing Program; Aircraft Guidance and Navigation Activity; General
Aviation/Commuter Technology; and Human Factors, Ames Research
Center

MARCH

16 Aerospace Safety Advisory Panel Presentation to the Senior Management
Council, NASA Headquarters

22 Review of Space Station/Russian Programs, NASA Headquarters

23 Review of Total Quality Management, NASA Headquarters

23 Aerospace Safety Advisory Panel Annual Meeting, NASA Headquarters

24 Review of NASA Safety Programs with Office of Management and
Budget, Washington, DC

APRIL

5-7 STS-59 Mission Activities, Kennedy Space Center

15 Review of Improved Auxiliary Power Unit, Sundstrand, Rockford, IL

MAY

10 Solid Rocket Motor Review, Thiokol, UT

11 Filament Wound Case Review, Hercules, Salt Lake City, UT

17-19 Reviews of Multi-Function Electronic Display System and Space Station,
Johnson Space Center

31 Intercenter Aircraft Operations Panel Meeting, El Paso, TX

JUNE

- 28 Review of Space Shuttle Main Engine Testing, Stennis Space Center
- 29 Review of External Tank Programs, Michoud Assembly Facility

JULY

- 1 Review of Office of Safety and Mission Assurance role in safety certification; Review of Space Shuttle/Mir Safety; Space Shuttle reliability discussions with Japanese News Agency, NASA Headquarters
- 15 Perseus A Flight Readiness Review, Dryden Flight Research Center
- 21 Software Process Action Team Meeting, NASA Headquarters

AUGUST

- 2 Perseus B Flight Readiness Review, Dryden Flight Research Center
- 8 Discussions with Administrator re Russian safety program; Assured Crew Return Vehicle policy; ASAP position on Improved Auxiliary Power Unit; aging aircraft; Solid Rocket Motor nozzle manufacturing; Human Factors Research, NASA Headquarters
- 9-10 Review of wind shear/wake vortex program; flight deck research/simulators; aging aircraft; tire wear and crash safety; High-Speed Research Program; Zero Visibility Landing, Langley Research Center
- 15-18 Review of structured surveillance progress; receipt and handling of Russian hardware; quality control for European supplied hardware; Space Station Processing Facility, Kennedy Space Center
- 17 Software Process Action Team Meeting, NASA Headquarters
- 31 Review of Improved Auxiliary Power Unit, Sundstrand, Rockford, IL

SEPTEMBER

- 12-13 Review of Fire Safety Research; Aircraft Operations; US/Russian Solar Dynamic Power System; Launch Vehicles; Aeronautics; and Chemical Rockets, Lewis Research Center
- 19 Letter Report to the Administrator, New Gas Generator Valve Module and Auxiliary Power Unit
- 27 Letter Report to the Administrator, Measures of Safety

OCTOBER

- 4-5 Integrated Logistics Panel Meeting, New Orleans, LA
- 18 Safety Program Review, Dryden Flight Research Center
- 19 Space Shuttle Main Engine and Manufacturing Processes and Supplier Management Reviews, Rocketdyne, Canoga Park, CA
- 20 Review of Orbiter return to launch site; tiles; Global Positioning System; Multi-Function Electronic Display System; and Space Shuttle/Russian Program, Rockwell, Downey, CA

NOVEMBER

- 8-9 Integrated Logistics Panel Meeting, Kennedy Space Center
- 9-10 Review of the Space Station Program; Russian Safety Process; Assured Crew Return Vehicle; and Shuttle/Mir, Johnson Space Center
- 16-17 Review of TU-144 Program and Shuttle/Mir, NASA Headquarters
- 23 Review of Microwave Scanning Beam Landing System, Rockwell, Downey, CA
- 30 Review of the Shuttle/Mir Docking Mechanism, NASA Headquarters

DECEMBER

- 5
WV Review of NASA Independent Verification and Validation Lab, Fairmont,
- 14-17 Panel Plenary Session, NASA Headquarters

JANUARY

- 9 Review of safety functions, Kennedy Space Center
- 18 STS-63 Flight Readiness Review, Kennedy Space Center

